DoD Key Technologies Plan

Director of Defense Research and Engineering

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INTRODUCTION AND OVERVIEW

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A. OBJECTIVE

In the aftermath of the Cold War, U.S. defense and acquisition strategies seek to prepare for potentially dangerous regional challenges while retaining the capability to respond globally if necessary. Toward that end, the Department of Defense is investing in a robust science and technology (S&T) program, and the Director, Defense and Engineering, has produced the Defense Science and Technology strategy. This strategy is based upon seven thrusts which are oriented toward significant improvements in warfighting capability. Central to obtaining that capability is the conduct of Advanced Technology Demonstrations (ATDs). These demonstrations range from assessing the military utility of new technological concepts in the laboratory to integrating and evaluating technology in as realistic operational environment as possible. Eleven Key Technology Areas have been identified as essential to obtaining the objectives of the ATDs identified in the strategy. Table 1 briefly describes each of the Key Technology Areas and the remainder of this document presents a corporate-level plan for developing these technologies so that the technology base program responds to the needs of the Seven Thrusts of the S&T Strategy.

The primary objective of these technology development plans is to prove out and mature the technologies required to attain the goals of the S&T Strategy thrusts. The activities delineated in this plan involve proof of concept experiments, laboratory demonstrations, and evaluations supported by models and simulations. These projects are primarily conducted in Budget Categories 6.1, Research, and 6.2, Exploratory Development. There is a limited amount of technology, however, which is sufficiently mature to warrant funding under Budget Category 6.3A, Advanced Developments.

Table 1. Descriptions of Key Technology Areas

Technology Area	Description
1. Computers	High performance computing systems (and their software operating systems) providing orders-of-magnitude improvements in computational and communications capabilities as a result of improvements in hardware, architectural designs, networking, and computational methods.
2. Software	The tools and techniques that facilitate the timely generation, maintenance, and enhancement of affordable and reliable applications software, including software for distributed systems, data base software, artificial intelligence, and neural nets.
3. Sensors	Active sensors (with emitters, such as radar and sonar), passive ("silent") sensors (e.g., thermal imagers, low light level TV, and infrared search and track systems), and the associated signal and image processing.
4. Communications Networking	The timely, reliable, and secure production and worldwide dissemination of information, using shared communications media and common hardware and applications software from originators to DoD consumers, in support of joint-Service mission planning, simulation, rehearsal, and execution.
5. Electronic Devices	Ultra-small (nano-scale) electronic and optoelectronic devices, combined with electronic packaging and photonics, for high speed computers, data storage modules, communication systems, advanced sensors, signal processing, radar, imaging systems, and automatic control.
6. Environmental Effects	The study, modeling, and simulation of atmospheric, oceanic, terrestrial, and space environmental effects, both natural and man-made, including the interaction of a weapon system with its operating medium and man-produced phenomena such as obscurants found on the battlefield.
7. Materials and Processes	Development of man-made materials (e.g., composites, electronic and photonic materials, smart materials) for improved structures, higher temperature engines, signature reduction, and electronics, and the synthesis and processing required for their application.
8. Energy Storage	The safe, compact storage of electrical or chemical energy, including energetic materials for military systems.
9. Propulsion and Energy Conversion	The efficient conversion of stored energy into usable forms, as in fuel efficient aircraft turbine engines and hypersonic systems.
10. Design Automation	Computer-aided design, concurrent engineering, simulation, and modeling; including the computational aspects of fluid dynamics, electromagnetics, advanced structures, structural dynamics, and other automated design processes.
11. Human-System Interfaces	The machine integration and interpretation of data and its presentation in a form convenient to the human operator; displays; human intelligence emulated in computational devices and simulation and synthetic environments.

B. RELATIONSHIP TO THE SCIENCE AND TECHNOLOGY STRATEGY

The formulation of this Key Technology Plan is driven by the S&T Strategy. At the core of this strategy are the Seven Thrusts which focus the S&T program to address the users' most pressing military and operational requirements. These thrusts are:

- Global Surveillance and Communications
- Precision Strike
- Air Superiority and Defense
- Sea Control and Undersea Superiority
- Advanced Land Combat
- Synthetic Environments
- Technology for Affordability.

The relationship of the Key Technology Areas to the S&T Strategy thrusts is presented in Table 2. The table also contains the thrust leaders' assessment of the importance of the technologies to each thrust. To ensure that the matrix would convey meaningful information, the S&T thrust leaders were constrained to identify a single technology area of highest priority to achieving the goals of their thrusts, and two considered to be second priority. The priority that the thrust leaders assigned to the sensors, software, and communications networking technology areas reflects S&T Strategies focus on exploiting the explosion in the information technologies.

This plan provides technology development roadmaps for the development and maturation of the technologies needed to achieve the stated goals of the thrusts. The plan further provides for the investigation of innovative technologies that could have a significant impact on military performance across a broad spectrum of applications.

C. ORGANIZATION OF PLAN

The sections that follow contain detailed plans for each of the 11 key technology areas. The development of the individual technology area plans is under the auspices of a senior technologist in the Office of the Secretary of Defense. For each technology area plan, top level technology goals reflecting the needs of the thrusts are presented for the next 12 years. Roadmaps of the incremental technology objectives required to attain the technical goals are given for 1995, 2000, and 2005. The plan also presents a summary of activities in other government agencies and industry, along with a summary of leading

Table 2. Key Technology Areas Vis-a-Vis the Seven S&T Thrusts (6.2)

Key Technology Area / Thrust Area	(1) Computers	(2) Software	(3) Sensors	(4) Communi-cations Networking	(5) Electronic Devices	(6) Environ-mental Effects	(7) Materials and Processes	(8) Energy Storage	(9) Propulsion and Energy Conversion	(10) Design Automation	(11) Human-System Interfaces
(1) Global Surveillance and Communications	○	○	●	★	●	○	○	○	○	○	○
(2) Precision Strike	○	★	●	●	○	○	○	○	○	○	○
(3) Air Superiority and Defense	●	○	★	○	●	○	○	○	○	○	○
(4) Sea Control and Undersea Superiority	●	○	★	○	○	○	○	○	○	●	○
(5) Advanced Land Combat	○	○	●	●	○	○	★	○	○	○	○
(6) Synthetic Environments	○	○	○	○	○	○				●	★
(7) Technology for Affordability	○	●		○	○		●			★	○

★ Highest Priority ● Second Highest Priority ○ Very Important industrialized nations' capabilities. Funding information on major technology subarea investments and the relation of the funding to the DoD budget structure by program element is also given.

This plan is also intended to fulfill the requirements of PL 101-189, National Defense Authorization Act for Fiscal Years 1990 and 1991, as amended by PL 101-510, and serve as the 1992 edition of the Defense Critical Technologies Plan. The relationship of the Key Technology Areas to the 21 critical technologies in the May 1991 Defense Critical Technologies Plan is presented in the Appendix.

KEY TECHNOLOGIES PLANS

1. COMPUTERS

A. DESCRIPTION OF TECHNOLOGY AREA

1. Scope

Computer technology entails developing, assessing, and transitioning into use: digital high performance computing (HPC) processors, accelerators, systems; specialized computer systems for harsh and unusual environments; generic signal processors; and associated peripheral equipment. The goal is to advance the state of the art and state of the practice of data, information, and general purpose signal processing for military missions and systems. General purpose signal processors are included in this technology area. Sensor-specific signal processing is included under Sensor Technology. Artificial neural networks—including their processors, communications, and other related elements—and optical storage, interconnects, correlators, and processing elements are also included in this technology area.

Although this technology area emphasizes high performance computers, the aspects of other associated technologies (e.g., HPC software and algorithms and high performance computer networking) necessary to apply, evaluate, demonstrate, and transition them into productive high performance computing systems are also included.

2. Computer Technology Subareas

a. Scalable Parallel HPC Systems

Through the Defense Advanced Research Projects Agency (DARPA), DoD has fostered the development of a number of first generation scalable, parallel HPC systems. Some of these HPC systems are now commercially available.

Second generation HPC systems that are under development will improve computational and communications capability by orders of magnitude as a result of improvements in microelectronics, packaging, interconnects, architectural designs, networking, and computational methods. Embeddable versions of commercial HPC elements and systems, for weapon systems, will be developed.

b. Specialized Computing and Signal Processing Systems

This subarea addresses specialized processing requirements and processing requirements for harsh or unusual conditions, such as radiation intense environments, space platforms, high performance aircraft, brilliant weapons, and other systems which are shape/size/weight/power constrained. Unique processing methods [e.g., artificial neural networks (ANN)] and generic signal processing are included in this subarea.

c. Optical Processing

Optical processing encompasses digital optical processors, optical interconnects, hybrid electro-optical digital processing, optical associative memories, optical random access memories (RAMs), and optical disk systems. Optical-based systems provide massive storage and high demand processing applications, such as multi-sensor data fusion.

3. Assessment

a. Scalable Parallel HPC Systems

High performance computing and communications are essential base technologies that will drive or limit the conduct of virtually all science and engineering fields for the foreseeable future. In the last decade, advances in HPC technology fueled a tenfold increase in useful computing performance. R&D programs such as the Federal High Performance Computing and Communications (HPCC) Program, the DARPA HPC Program and other initiatives sponsored by the Services and Defense Agencies are currently seeking to accelerate advances in electronics, architectures, networking, software, applications, and other related HPC technologies. These programs will produce a thousand-fold improvement in useful computing capability and a hundred-fold improvement in available computer communications capability by 1996.

Average performance increases of 50 percent per year, sustained for the past 3 years, have produced computers capable of executing about 300 million operations per second (megaops) as uniprocessor vector machines. These processors have been used in small scale shared memory multiprocessors such as the Cray Y-MP, which can sustain about 2 billion operations per second (gigaops). Scalable parallel computer architectures will play a key role in maintaining this momentum. Advanced integrated microelectronics technologies and the corresponding reductions in cost of microelectronic devices have made large-scale parallel systems feasible, opening a path to systems of even higher performance. Performance is expected to exceed one trillion operations per second (teraops) by the mid-1990s as a result of the Presidential Initiative in High Performance Computing and Communications. Teraops computing systems will require billion bit per second networks to ensure a balanced high performance computing technology base. These multiple use high performance computing and communications technologies are critical to developing future Defense capabilities.

The DoD HPC Program is an integral part of the Federal Government High Performance Computing and Communications Program, which also includes efforts by the National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), Department of Energy (DoE), Department of Health and Human Services/National Institutes of Health (HHS/NIH), Department of Commerce/National Oceanic and Atmospheric Administration (DoC/NOAA) and National Institute of Standards and Technology (DoC/NIST), and Environmental Protection Agency (EPA). As the DoD element of the HPCC program builds up, the ongoing DoD HPC Program will focus on more defense-specific needs, such as embedded systems, accelerators of specific problem domains, and critical problems related to defense.

For undersea surveillance generalized modules have already been developed; new spatial processing algorithms will soon be available, and an array element location capability will be demonstrated by FY93. For acoustic Fixed Distribution System (FDS) visualization, DoD has implemented highly parallel meshes for mapping and will demonstrate a human-engineered display workbench with an integrated High Definition Display. Command, Control, and Communications (C^3I) application efforts have formulated optimal selection theory. A Navy training demonstration will be conducted shortly which includes implementation of distributed data bases on parallel computers. Development efforts are also focused on signal processing for infrared (IR)/focal plane array (FPA) sensors. An alternative sensor processor will be prototyped and evaluated by FY93 and an optimized parallel commuting design and algorithm approach demonstrated in FY94. The major objective of DoD's development program in parallel computer architectures and high performance computing is to develop the component, packaging, and design technologies for large-scale and embeddable high performance computing systems. Development of embeddable systems from this technology is a major element of the plan.

The University of Minnesota has established an Army High Performance Computing Research Center. This center is a 5-year contractual effort involving the acquisition and networking of high performance computing architectures in a heterogeneous environment. Basic interdisciplinary research will be conducted in the optimal exploitation of problem structure and parallel architectures for solving problems in science and engineering. Expertise in parallel processing will be transferred from the center to DoD scientists through on-site tutorials, consulting, technical reports, and hands-on parallel computing experience. The development of parallel software systems required to support the center will directly affect productivity in parallel software development, which lags far behind developments in parallel processing hardware.

Evaluations of the performance of these new scalable HPC architectures on certain DoD critical high demand processing problems are under way in the DoD laboratories and research centers. These investigations are stimulating the development of entirely new computational methods for these problems.

b. Specialized Computing and Signal Processing Systems

In the area of Specialized Computing Systems, the Strategic Defensive Initiative (SDI) program has emphasized radiation hardened Complementary Metal Oxide Semiconductor (CMOS)/Silicon on Sapphire (SOS), and Silicon on Insulator microprocessors, vector, pipelined and special purpose attached processors. Research has concentrated on both Multiple Instruction Multiple Data (MIMD) and Single Instruction Multiple Data (SIMD) massively parallel multicomputers as well as artificial neural processors for both sensor signal processing and battle management and simulation. SDI has also emphasized radiation hardened static random access memories, non-volatile memories, analog-to-digital converters, precision voltage reference components, and power converters to be used in radiation hardened computer systems.

In signal processing, the DARPA/tri-Service Rapid Prototyping of Applications Specific Signal Processors (RASSP) Program will demonstrate the capability to rapidly specify, produce, and field domain-specific, affordable signal processors for a variety of defense system applications in a manner to allow for new technology insertion. The goal is to show that by properly partitioning such systems into an analog front end, a digital front end, and an embedded data processor and mass memory, the system can be upgraded regularly, i.e., "each model year," providing substantial improvement in system performance without requiring rework of either hardware or software for other parts of the system.

The RASSP approach is based upon: using a "seamless" design environment employing a standard hardware description language; appropriate partitioning of hardware and software functions; use of standard software and hardware interfaces to make the upgrade transparent (except for improved performance) to the user; and the ability to link the design system to be developed with flexible manufacturing and test capabilities of several integrated circuit chip and packaging vendors so that hardware procurement is not dependent on one source of supply.

DARPA-sponsored research has spawned a family of new Very Large Scale Integrated (VLSI) artificial neural network implementations for real-time signal classification, ATR, image compression, speech recognition, and robotics control. High performance, compact, low power neural computers are under development for a number of applications. The ability to classify across an acoustical array will be developed in a Navy demonstration of high performance VLSI neural networks for signal classification. Affordability will be addressed by a demonstration of neural network hardware integrated into onboard machinery diagnostics for helicopters and surface ships.

c. Optical Processing

In optical processing, DARPA has an extensive Optics in Computing program which encompasses the basic material and device technologies, opto-electronic interconnects for both digital and analog transmission, optical memories, optical correlators, and packaging of opto-electronic modules. SDI is developing materials and device support technologies, including photonics, superconductors, and compound semiconductors. Photonics efforts include optical interconnects in both bulk optics and waveguide optics, and gigabit computer networks. Storage technologies include optical mass storage and three-dimensional structures. Work in wide bandgap materials—silicon carbide, nitride and phosphide compounds, and diamond—support not only hardened hardware, but also extended performance devices. An extensive program exists in materials processing, new devices, monolithic wafer-scale packaging, and device reliability.

B. TECHNOLOGY AREA GOALS

Table 1-1. Computer Technology Goals

Subarea	By 1995	By 2000	By 2005
Scalable, Parallel HPC Systems	• Teraops systems (Tera = 10^{12}) available. • Gigabits/sec network performance. • Parallel software and scalable libraries. • 100 gigaops systems in DoD labs.	• 100 Teraops systems available. • Rapid manufacturing for special designs. • Petaops designs. • 100 gigabits/sec networks available • 10 teraops systems in DoD labs.	• Petaops systems available (Peta = 10^{15}). • Flexible reconfigurable hardware architecture. • Terabits/sec networks deployable.
Specialized Computing Systems	• Demo rad. hardened RH-32 RISC. • Flt. Test 10 gigaops ANN in imaging seeker. • Lab demo 1 cu. inch 300 mips, 5 gigaflops, • 0.5 gigabytes, 100 watts, processor based on wafer scale integration. • RASSP design/mfg. infrastructure for rapid upgrade of signal processors demo. • Initial system demo under way for ATR. • 1 to 2 gigaops performance for signal processors under RASSP.	• 100 gigaops ANNs available. • 1 cu. inch processor, 1500 mips, 25 gigaflops, 2 gigabytes, 150 watts. • RASSP design/mfg infrastructure in place for rapid upgrade of wide range of systems.	• Teraops ANNs available. • 1 cu. inch processor, 10 bips, 200 gigaflops, 10 gigabytes, 200 watts.
Optical Processing	• 12 gigabyte optical disk jukebox, 14" removable, erasable disks, millisec access, 50 Mbits/sec transfer. • Lab demo—10 gigaops hybrid processor, 10^{10} bit RAM— microsec access. • Switched interconnection network with gigabit/sec./channel.	• Compact 10 gigaops processor, 10^{10} bit RAM. • Lab demo—1 teraops processor, 10^{12} bit RAM—nanosec access. • Optical backplane with aggregate throughput of 64 gigabits/sec.	• Compact teraops processor, 10^{12} bit RAM. • Lab demo—100 teraops processor, 10^{15} bit RAM—nanosec access • Optical wide area networks at gigabits/sec./node.

C. RELATIONSHIP OF TECHNOLOGY GOALS TO THRUSTS

Table 1-2. Relationship of Computer Technology Goals to Thrusts

Thrust \ Subarea	Scalable, Parallel HPC Systems	Specialized Computing and Signal Processing Systems	Optical Processing
1. Global Surveillance and Communications	• Embedded teraops processing. • Gigabits/sec networks. • Distributed heterogeneous processing for command/ control.	• Signal processing at giga-flops, in 1 cu. inch. • ANNs at giga-teraops for imaging sensors-- improved sensor performance.	• Giga-terops sensor data processing, 10^{12} bit storage for multi-sensor fusion and sensor data recording.
2. Precision Strike	• Teraops processing for rapid mission planning, near real time targeting, and fire control.	• Gigaflop signal processors to improve sensors. • ANNs at giga-teraops for ATR, missile G&C, autonomous weapons. • Rapid signal processing up-grade capability (RASSP) for ATR, acquisition and track.	• Giga-teraops sensor data processing, 10^{12} bit storage for multi-sensor fusion.
3. Air Superiority and Defense	• Embedded teraops processing for multi-ATBMs and detection and tracking of reduced signature targets. • Embedded teraops for Avionics.	• Gigaflops signal processing to improve sensors. • ANNs at giga-teraops for fire and forget missiles. • Rapid signal processing upgrade capability.	• Gigabyte storage for sensor recording. • Signal processing of low observables.
4. Sea Control and Undersea Superiority	• Embedded teraops for surface and Undersea C^2. • Embedded teraops for unmanned undersea and air vehicles. • Gigabits/sec networks.	• Gigaops signal processing for acoustic and non-acoustic sensors. • ANNs for smart weapons. • Rapid signal processing up-grade capability.	• Signal processing for ASW. • Gigabit-teraops processing and gigabyte storage for ocean models processing and environmental effects.
5. Advanced Land Combat	• Teraops processing for C^2 and battle management, and "expert assistants" for com-manders and crew chiefs to reduce workload. • Distributed heterogeneous processing. • Gigabits/sec networks.	• Gigaflop signal processing for sensor enhancement. • ANNs for fire and forget weapons.	• Image processing for un-manned vehicles.
6. Synthetic Environments	• Teraops processing in simu-lation centers for model development and execution. • Gigabit network for connectivity.	• Special processors embed-ded in simulators.	• Massive - 10^{15} bit RAMs for storage/retrieval of real world scenes and scenarios.
7. Technology for Affordability	• HPC for industrial C^2. • High performance LANs for factory floor integrated control.	• Signal processing technology transitioning to industrial sensors. • RASSP design/mfg infra-structure for rapid upgrade of signal processors.	• Massive memories for design storage, reusable S/W components, etc.

D. SUBAREA ROADMAPS TO REACH TECHNOLOGY GOALS

Table 1-3. Roadmap of Technology Objectives for Scalable Parallel HPC Systems

Technology Set	By 1995	By 2000	By 2005
High Performance Computing Systems	• Teraops systems (Tera = 10^{2}). • Multichip modules packages. • Heterogeneous • systems. Multi teraop designs.	• 100 teraops systems. • Rapid manufacturing for special purposes. • Optical interconnect. • Petaops designs.	• 10 petaops systems (peta = 10^{15}). • Flexible reconfigurable hardware architecture.
HPC Software Technology and Algorithms	• Scalable libraries. • Design tools. • Support for heterogeneous computing.	• Programming environments integrated with software engineering for scalable systems deployed in defense facilities.	• Advanced programming environments for scalable systems.
High Performance Networking	• Gigabit networks available for deployment. • Multi-gigabit designs.	• 100 gigabit available for deployment. • Terabit designs with all optical data paths.	• Terabit deployable.
Basic Research and Human Resources	• 100 teraops component research. • 10 teraops lab. scale system demos.	• 10 petaops components research. • Petaops systems research.	• 100 petaops component research.
Defense-Specific Technologies	• Embedded systems with 10 gigaops/ft^3 & 100 gigaops component technology.	• Embedded systems with 40 gigaops/ft^3 & teraops component technology.	• Embedded systems with 100 teraops component technology.
HPC Modernization and Sustainment	• 100 gigaops systems in labs.	• 10 teraops systems in labs.	• Petaops systems in labs.
Applications and Evaluations	• Applications of 100 gigaops systems.	• Applications of 10 teraops systems.	• Applications of petaops systems.

Table 1-4. Roadmap of Technology Objectives for Specialized Computing and Signal Processing Systems

Technology Set	By 1995	By 2000	By 2005
Radiation Hardened Computing Systems	• Demo 32 bit—Reduced Instruction Set Computer (RISC), RH-32.	N/A	N/A
Space and Airborne Computing Systems	• Demo Adv. Spaceborne Computer Module (ASCM)—Mil STD 1750-A processor 250 cu. in., 12 lbs 60 watts.	N/A	N/A
Digital Avionics	• Design of distributed system scalable, parallel and heterogeneous processors for avionics.	• Lab [illegible] of distributed [illegible] scalable, parallel and heterogeneous processors for avionics.	• Distributed scalable, parallel and heterogeneous systems available for avionics.
Artificial Neural Networks (ANN)	• Flight test 10 gigaops ANN in imaging seeker.	• 100 gigaops ANNs available for smart weapon applications (e.g. fire & forget missiles).	• Teraops ANNs available.
Generic Signal Processing	• Lab demo 1 cu. inch, 300 mips 5 gigaflops, 100-watt processor based on wafer scale integration.	• Lab demo 1 cu. inch, 1500 mips 25 gigaflops, 2 gigabytes, 150-watt processor.	• Lab demo 1 cu. inch, 10 bips, 200 gigaflops 10 gigabytes, 200 watt processor.

N/A = Not applicable.

Table 1-5. Roadmap of Technology Objectives for Optical Processing

Technology Set	By 1995	By 2000	By 2005
Optical Disk Systems	• 12 gigabyte optical disk juke box, 14" removable erasable discs, millisec access, 50 megabits/sec transfer rate. • Transition to ESC.	• Not applicable.	• Not applicable.
Optical 3-D Memories	• Demo optical associative memory characterisitics. • Lab demo of 10^{0} bit RAM with microsec access.	• Compact 10^{10} bit optical RAMS available. • Lab demo of 10^{12} bit RAM with nanosec access.	• Compact 10^{12} bit optical RAMS available. • Lab demo of 10^{15} bit RAM with nanosec access.
Optical Processors	• Lab demo of 10 gigops processor.	• Compact 10 gigaops processor available. • Lab demo of one teraops processor.	• Compact teraops processor available. • Lab demo of 100 teraops processor.
Optical Interconnects	• Switched interconnection network with gigabits/sec/channel.	• Optical backplane with aggregate throughput of 64 gigabits/sec/node.	• Optical wide area networks at gigabits/sec/node.

E. R&D IN OTHER ORGANIZATIONS (GOVERNMENT, INDUSTRY, FOREIGN)

1. Government

The overall High Performance Computing and Communications (HPCC) Program is a multiagency Federal program to advance the frontiers in computer and communications technologies. It is formulated to satisfy national need from a variety of perspectives: technology, science applications, human resources, and technology transition. Needs are derived from the participating agencies' missions. Many of these mission needs are related to solving very intensive large-scale computing problems. The program is implemented as a partnership among the participating agencies with leadership and oversight provided by the Office of Science and Technology Policy. The full program is described in a report "Grand Challenges 1993: High Performance Computing and Communications, The FY 1993 U.S. Research and Development Program" prepared by the Committee on Physical, Mathematical, and Engineering Sciences of the Federal Coordinating Council on Science, Engineering and Technology.

DARPA, as DoD's agent, is responsible for development of the technology for computing systems and computer communications. DoD/DARPA specific activities are discussed above. Other HPCC Program participating agencies' activities are highlighted below.

The DoE has active programs in a number of parallel computer architecture areas:

- Robust computing infrastructures.
- Methods development and implementation for major applications.
- A small number of experimental supercomputing centers established through the national laboratories.
- Use of government research centers in educational initiatives.

DoE in particular is fostering education through a series of post-doctoral and pre-doctoral fellowships and through its efforts to provide a center for parallel computing that would be open to researchers and students from other institutions (a DARPA/INTEL collaboration in DARPA's Touchstone project, networking collaborations with AT&T Bell Labs, and architecture research collaborations with industrial firms). DoE research at universities focuses on parallel algorithms, software development environment and techniques for parallel machines, and instrumentation and monitoring techniques for parallel architectures. University research is also concentrating on the development of parallel programming environments to permit effective utilization of parallel computer architectures, especially for scientific computing applications. A major research program to develop an integrated programming environment for shared memory architectures is under way at the University of Illinois.

NASA is actively supporting the development and utilization of parallel computer architectures. Driven by agency mission requirements, NASA developed an early large-scale parallel computer, the Massively Parallel Processor (MPP). The technology developed and the lessons learned have transitioned to several commercial successors to the MPP.

NASA is currently integrating a number of parallel processors into its institutional computer centers such as the Numerical Aerodynamic Simulation Facility at the Ames Research Center. Processors are both large grain and fine grain parallel. NASA invests even more of its annual budget in the development of algorithms, applications, and system software for parallel processing in its field centers, research institutes, and university-based centers of excellence. The list of the facilities developing or utilizing parallel processors under NASA funds includes (but is not limited to): Ames, Lewis, and Langley Research Centers; Goddard Space Flight Center; Jet Propulsion Laboratory; Stanford University; and the University of Illinois.

The objective of the National Institute of Standards and Technology (NIST) Performance Measures for Advanced Computers program is to devise ways of measuring the performance characteristics of high performance multi-processor machines, particularly multiple-instruction machines based on shared and distributed memory architectures, without significantly degrading the performance. Studies to date demonstrate that the performance of a system may be characterized by a few system state parameters, thus indicating that compact, predictive models of performance are possible. NIST's responsibilities in the Federal High Performance Computing Program are to promote "open" software systems and support a classification system for indexing and distributing scientific software so that industry and the research community can effectively exploit the power of future generations of high performance computers.

NSF support for research on parallel computer architecture is provided primarily through activities in computer and computation theory, computer and microelectronics systems architecture, software systems and engineering, and experimental systems. In addition, NSF funds the Center for Research on Parallel Computation. Researchers are provided access to massively parallel computers at four NSF supercomputer centers.

DoC/NOAA is investigating parallel computing for weather prediction, ocean sciences, the Climate and Global Change Research Program, and the Coastal Oceans Program. Development of advanced numerical models for simulating the general circulation of the oceans and atmosphere will lead to better forecasting models in support of NOAA's mission.

HHS/NIH integrates parallel computing with computationally intensive biomedical research applications, such as the Human Genome Project, links academic health centers via computer networks, creates advanced methods to retrieve information from life sciences data bases, and provides training in biomedical computer sciences.

EPA's program is incorporating advances in parallel computing and communications technology into its environmental assessment programs. These advanced environmental assessment tools will be capable of handling multiple pollutant reactions including the air/water interchange and permit optimization of pollutant control strategies.

2. Industry

Defense investment in high-performance parallel computing has spawned a number of industrial product lines, mostly oriented toward commercial applications. In the past industry has generally considered exploitation of massive parallelism into the teraops range as too risky for development. Instead, U.S. industry has pursued incremental improvements in older approaches to computing. University research is concentrating on the development of parallel programming environments to permit effective utilization of parallel computer architectures for scientific computing applications.

As a result of DARPA's efforts to share DARPA-sponsored research results with U.S. industry, first generation scalable parallel systems are now commercially available from U.S. vendors. Makers of parallel computing equipment fall into two principal categories: supercomputer vendors (there are 6 domestic firms) and minisupercomputer vendors (approximately 23). Since 1976, the supercomputer market has been one of the most stable high technology growth markets, with growth estimated at 7 percent annually from 1989 to 1992, while the minisupercomputer market grew 28 percent annually during the same period. As a result of DARPA investments in the 1980s, a new industrial base in development and use of scalable parallel computers has begun to emerge. Although the market is still small, it is considered a critical enabler of a broad range of critical defense capabilities.

Specific plans related to manufacturing technology will be driven by growing market pull from large commercial and scientific markets that were once the exclusive domain of the mainframe and are moving rapidly to scalable, parallel processing. Most U.S.-based supercomputers and nearly all minisupercomputers have introduced parallel architectural concepts into their systems. Because of increased emphasis on advanced computing by Japanese computer manufacturers (with strong government backing), a highly competitive environment will be evident.

3. Foreign

a. Status of Technology

There is no evidence that the former Soviet states have achieved significant success in high-performance computing. They have historically lagged the United States by 10 or more years in computer systems, and there is no indication this will change. The former Soviet states are, and will continue to be, severely hampered by lack of capability for quantity production of high-speed digital components and assemblies. Thus, their strengths are likely to remain largely in theory, research, and prototyping. Major HPC activity in the former Soviet Union (FSU) includes a variety of different architectures: Elbrus 1 and 2, Elbrus 3, MARS, M-10, PS-2000, PS-3000, SSBIS, TAGREI, ES-1766, and two Bulgarian-led machines—the IZOT-1703 and IZOT-1014E. While they have had a significant research effort in parallel computing, the states of the FSU are many years from being able to provide their scientists and engineers with the levels of technology available to their Western counterparts.

The increased availability of microprocessors enables the development of early forms of scalable parallel systems. The United States, Europe, and Canada are pursuing parallel computing through increasing integration of processors. Japanese efforts have emphasized peak vector processor performance. As a consequence, Japan has not produced massively parallel machines on a par with the United States, Europe, and Canada. However, their multi-processor computers have a much higher theoretical peak performance (TPP) than do their U.S., European, and Canadian counterparts. U.S. technology continues to be dependent on Japanese memory chips and some high performance component technologies. The processing components of all advanced U.S. scalable parallel computing systems are designed and produced by U.S. sources.

Cooperative opportunities will exist with NATO countries, especially the United Kingdom, the Netherlands, Germany, and France.

Japan, the U.K., the Netherlands, and Germany all have credible efforts in parallel computing. The Japanese have developed high peak performance production models of small parallel processing vector computer systems. NEC's SX-X/SX-3/3/44 series of computers, released in 1989, has four processors capable of a TPP of 22 gigaflops. However, the Japanese are several years behind the U.S. in highly parallel systems and associated software. As the commercial market becomes more significant, the Japanese can be expected to try to close the gap. The U.S. systems can generally sustain higher performance for important applications than Japanese systems can sustain.

Japanese R&D in parallel computing is beginning to show results The Industrial Technology Agency's Electrotechnology Laboratory has announced the development of a 128-processor configuration dataflow system, the Sigma-1, a hardware prototype based on an earlier dataflow design developed at the Massachusetts Institute of Technology. The Japanese have developed only minimal demonstration software for this system. The stated maximum processing speed is 640 million floating point operations per second (megaflops), placing the system in the supercomputer category. The Japanese efforts do not compare to the breadth and depth of U.S. projects. They have no effort equivalent to the U.K. transputer project described below.

The U.K. has supported a significant parallel processing software research effort and infrastructure in its universities, industry, and government establishments. Notable among these is the Alvey Program for Advanced Information Technology. The European Strategic Program for Research in Information Technology (ESPRIT) is also pursuing related software engineering initiatives. Specific areas of research include techniques for dynamic control of array topology and diagnosis and control of load balance in massively parallel processors. The Edinburgh concurrent supercomputer is presently using an electronically reconfigurable 200-processor array of Inmos transputers (3 megaflops per processor board) for a wide range of research and modeling applications. The ESPRIT project also uses the Inmos transputer and supports research in many areas. Applications include development of high-level programming languages and techniques for image processing and syntheses, scientific computation (including computational fluid dynamics), logic simulation, and artificial neural networks.

The U.K. was a primary contributor to the development of the OCCAM-I, -II programming languages, the first general computer language written specifically for parallel computers. Inmos, Ltd. (Bristol, England), developed and now produces a line of VLSI chips specifically designed to implement the OCCAM language. These transputers are the building blocks of a research program being pursued by the Royal Signals and Radar Establishment with support from Thorn EMI, Ltd., Inmos, and South Hampton University to develop a real-time reconfigurable supercomputer.

Many other countries, including Russia, Germany, Hungary, Czechoslovakia, and Denmark, are involved with parallel computer architecture research based on the Inmos transputer. Hungary is working on a distributed version of PROLOG for transputers called CS-PROLOG, and Germany is researching the use of transputers in space technology to process the enormous amounts of data collected on board spacecraft. Recently the Netherlands has become much more active in the field, especially in the areas of algorithms and the application of parallel architectures to artificial intelligence.

China has continued HPC R&D since it first announced the Galaxy supercomputer in December 1983. Four years later came the first dataflow prototype and an 8-node hypercube. Two more recent computers are the 980 STAR, which has a 100-Mip systolic array, and an 80-Mip machine based on transputers and RISC chips.

A few HPC projects are under way in Australia, Canada, India, and South Korea. Japan has notably more activity involving its industry, government facilities, and academia.

The former Soviet states, mainly Russia, have had a strong program in optical computing and optical image processing. They have built different optical memories in laboratories, such as holographic multichannel superimposed disks, multiple disk set, and fiber optic memory. Regarding components, they have notable achievements in spatial light modulators (both optically and electronically addressed) and diffractive optical elements. Other pertinent R&D includes optical interconnections and holographic waveguides. In general, the FSU has done more physics work in materials than the West.

The Japanese are building their knowledge base in this technology while gaining experience with production of devices, particularly optical memories. Under the New Information Processing Technologies (NIPT) project, which began in March 1991, the Japanese were to investigate information processing technology to include optical neurocomputers and optical parallel digital computer architectures. NIPT plans call for a 10-year project with annual funding of up to $40 million.

European programs are centered in France, Germany, and the U.K. and reflect cooperation between industry and academia. The Universitat Erlangen in Germany is a leader in general purpose optical computing. The Delft University of Technology, Netherlands, is applying optical interconnections and simple processing in conjunction with electronic computers. Others are doing research on optical interconnections under the ESPIRIT project, Optical Interconnections for VLSI and Electronic Systems (OLIVES). OLIVES is a 5-year program begun in 1989. Using French and U.S. components, both Norway and the U.K. have built optical memories for storing satellite imagery.

b. Exchange Agreements

Mechanisms for international cooperation in military applications of parallel computing are still developing in this relatively new field. The NATO Defense Research Group (DRG) programs in operations research and in long-term research for air defense provide a mechanism for exchanges of information to help understand and define essential requirements for future applications of parallel computing. The Technical Cooperation Program provides a direct vehicle under its program for machine and system architecture and for a range of applicable machine activities under computing technology, software engineering, and trusted computer systems.

The Services also have exchanges, primarily with NATO and a few other friendly nations. Ongoing Service exchange programs in distributed command and control, signal processing, flight control, cockpit systems for advanced fighters and helicopters, and computational fluid dynamics support parallel computer architecture technology. DARPA and NSF jointly sponsored an exploratory workshop with ESPRIT on a variety of topics including High Performance Computing.

Table 1-6. Summary and Comparison — Computers

Subarea	NATO Allies	Japan	CIS	Others
1. Scalable Parallel HPC Systems	□□□	□□	□	□□ Includes China, India, Israel, and S. Korea
2. Specialized Computing Systems	□□ O	□□□ O[a]	□	□
3. Optical Processing	□□ O	□□□ O	□□□ –	□ China
Overall[b]	□□	□□□ O	□□	□

[a] Japan's niche is in artificial neural networks.

[b] The overall evaluation is a subjective assessment of the average standing of the technology in the nation (or nations) considered.

LEGEND:

Position of other countries relative to the United States:

- □□□□ Broad technical achievement; capable of major contributions
- □□□ Moderate technical capability; possible leadership in some technical niches; capable of important contributions
- □□ Generally lagging; may be capable of contributing in selected areas
- □ Lagging in all important aspects; unlikely to contribute prior to 2002

Trend indicators—where significant or important capabilities exist (i.e., 3 or 4 blocks):

- \+ Foreign capability increasing at a faster rate than the United States
- O Foreign capability increasing at a similar rate to the United States
- – Foreign capability increasing at a slower rate than the United States
- ? Currently unable to assess rate of change in foreign capability vs. the United States

F. FUNDING

Table 1-7. Funding by Subarea
($ in Millions)

Subarea	FY92	FY93	FY94
Scalable, Parallel HPC System*	237	280	358
Specialized Computing and Signal Processing Systems	43	98	65
Optical Processing	30	33	35
TOTAL	310	411	458

*Includes the DARPA-led, DoD portion of the Federal High Performance Computing and Communications (HPCC) program, and Services' evaluations of HPC systems.

Table 1-8. Funding by Program Element
($ in Millions)

PE No.	Title	FY92	FY93	FY94
601101E	Defense Research Sciences	51.7	61.9	76.7
602204F	Aerospace Avionics	0.0	0.2	0.4
602234N	System Support Technology	3.2	3.1	3.1
602301E	Computing Systems and Communications Technology	206.4	255.2	305.4
602618A	Ballistics Technology	1.4	1.8	1.8
602702F	Command, Control, and Communications	3.0	3.9	4.4
602712E	Materials and Electronics Technology	1.2	4.6	8.0
603214C	Space-Based Interceptors	2.2	4.0	5.0
603215C	Limited Defense System	28.3	41.0	41.9
603218C	Research and Support Activities	8.0	8.0	8.0
603253F	Advanced Avionics Integration	0.0	0.1	0.5
603726F	C3I Subsystem Integration	4.3	3.8	3.0
603739E	Electronics Manufacturing	0.6	23.1	0.0
	Total	310.3	410.7	458.2

2. SOFTWARE

A. DESCRIPTION OF TECHNOLOGY AREA

1. Scope

For the purposes of this Key Technologies Plan, the scope of this technology area includes the tools and techniques that facilitate the timely generation, maintenance, and enhancement of affordable and reliable applications software, including software for distributed systems, data base software, artificial intelligence, and neural nets. It includes software-intensive systems technology for rapid user-interface prototyping, computer system performance models, and generic domain-oriented software architectures. However, design and prototyping technology for specific products, overall weapons systems performance models, and specific weapon-system technology applications are not included. High performance computing systems (and their operating systems) are addressed in the Computer Technology Area of this plan.

2. Software Technology Subareas

a. Software and Systems Engineering

Software and Systems Engineering includes the process and associated software tool support for all phases of the software and system life cycle, from user requirements formulation through software design, development, integration, test and evaluation, rework, deployment, logistics, repair, reengineering, and reuse. Software engineering (which is considered in the overall context of systems engineering because the "smarts" of major defense systems are usually embodied in the software) refers to the processes by which software components and systems are synthesized to meet user information processing needs. Key elements of this subarea include process management support, software and systems engineering tools and environments, software reuse and reengineering, and information engineering.

b. Human-Computer Interaction

Human-Computer Interaction (HCI) software is the portion of a system that implements the user interface. It provides the critical communication link between the human user and the computational technology tool. HCI research is multidisciplinary, requiring complementary software and human system interface perspectives. Software technology advances needed for improved HCI are addressed in this section of the plan, whereas the human-centered efforts are addressed in the Human-System Interfaces Area.

c. Artificial Intelligence

Artificial Intelligence (AI) enables computers to solve problems (or assist humans in solving problems) using explicit representations of knowledge and reasoning methods employing that knowledge to extract new or implied knowledge. The development of reasoning methods and the development of representation and content of the domain knowledge upon which they act are closely intertwined. AI offers methods for successfully attacking problems for which conventional algorithmic processes are inadequate. AI techniques are particularly well suited to capturing human problem-solving knowledge and to interacting with humans in decision-making systems.

d. Software for Parallel and Heterogeneous Distributed Systems

Software for Parallel and Heterogeneous Distributed Systems includes operating systems (except those for high performance computing addressed in Computers), distributed data bases and file systems, software development tools, and algorithm support to realize potential gains in sophistication, robustness, accessibility, and usefulness of DoD systems.

e. Real-Time/Fault-Tolerant Software

Real-time software is software whose correctness depends not only on the results of computation, but also on the time at which the results are produced. Fault-tolerant software includes functions for detecting, identifying, confining, and/or recovering from faults to create a system that will continue to provide computing services despite faults or failures of hardware or software components. The technologies to support real-time software and fault-tolerant software have, for the most part, evolved separately. Efforts to bring the two technologies together have only recently been initiated. Real-time/fault-tolerant (RT/FT) software enables software to deliver results accurately, reliably, and timely, in spite of heavy demand or failure of system elements.

f. High Assurance Software

High assurance software is software for which there is compelling evidence that the computer system will respond properly under all required circumstances with respect to specific high assurance criteria, such as security, safety, or timeliness. Secure software is software that has a level of assurance that the system can enforce a specific security policy relating, for example, to confidentiality, integrity, or access. Safe software "assures" that the system will not enter a hazardous state. Other system properties that may need to be assured include integrity, availability, liveliness, and fault-tolerance.

3. Assessment

a. Software and Systems Engineering

There is currently no single software process model that will support the full diversity of development and post-deployment activities. Unprecedented systems call for tailorable and iterative process models that support flexible prototyping and requirements engineering. Process models must also address software reuse, control and management of requirements, and ongoing assessment of risks, costs, and schedule. Metrics for cost, schedule, quality, and process are also required to provide improved estimation and greater insight into the development process. Therefore, current DoD efforts in process management support emphasize process and acquisition models; process and acquisition assessment and risk management; management practices, procedures, and techniques; and metrics for cost, schedule, quality, and process. Focused effort in these areas is supported by scientific research in risk analysis; cost estimation modeling; process design, codification, and tailoring; adaptive cost and schedule models; and proactive management methods.

Because software environment and tool technology is the principal means to manage software processes for large systems and to implement software management solutions, the DoD is supporting major thrusts in software environments and tools through efforts in proactive management aids; software prototyping; multilanguage interoperability in a heterogeneous environment; formal methods; advanced software environment integration mechanisms; software quality technology, including testing and verification; programming language foundations; software understanding; and advanced tool approaches. In addition to the gains achievable through process management support and software environments, a significant potential cost savings and risk reduction is available to the DoD through the development of architectures, interfaces, and components that can be effectively reused and reengineered for multiple uses. As reengineering technology improves, it may also be possible to make effective reuse of components from existing systems that may not have originally been designed to be reusable. Current DoD efforts in reuse and reengineering include software architecture engineering, software understanding, and process and methods for reuse and reengineering.

Information engineering involves integration, processing, and maintaining large amounts of information, possibly in diverse locations, in support of business decisions and actions. The principal challenge for DoD in this area is to effectively exploit commercial technologies and, where appropriate, to stimulate the commercial market to respond to particular DoD needs. An additional challenge is the modernization and integration of the many existing large-scale DoD data bases to support the more flexible and robust processes required in the current DoD environment. Therefore, current DoD efforts in information engineering are focused on information models and principles, information storage and sharing, information systems architectures and interfaces, and analysis and decision support and engineering.

b. Human-Computer Interaction

While the entire scope of a user interface spans multidisciplinary approaches, HCI software technology focuses on the hardware interfaces and software interfaces that provide the communication facility between the user and the task environment. These two aspects of the technology, user and task, provide the major thrusts of HCI research and technology development. The overall goal of HCI technology development in the human-hardware areas is to support effective and efficient communication between human users and computer-based systems. Historically, this has been the primary focus of HCI development.

Engineering solutions of devices to produce suitable representations for communication have been developed as better electronic/optic/audio technology has emerged. These devices are generally aided and constrained in their design by knowledge from human factors research. HCI software technology includes two fundamental parts: (1) software concepts and techniques for designing a task-specific software interface; and (2) software engineering tools for prototyping and building user interfaces. Developing and representing design principles and techniques are basic to enabling interface designers to specify and employ usable, effective interfaces. Software engineering tools for interface specification will enable software developers to design and build software systems that satisfy current requirements and easily adapt to meet new ones at all levels of the system specification, from hardware interfaces through user task interfaces.

Much of the focus of the current state of HCI technology is based on the current mode of computer use in decision-based systems. The systems are often single application for a single user or are multiple applications directly controlled by a single user, as represented by workstation or personal computer environments. Most of the HCI-related research in the DoD is conducted as part of larger programs or within other software technology subareas. The focus of the DoD strategy in HCI technology is to enable an expanded view of the computational facility support, to include extremely complex integration across the current level of facility. At the individual level it includes an integrated task process environment that may or may not use distributed resources. Integration across individual task environments would create a multitask integrated perspective that could be used for multiple purposes (e.g., analysis, prediction, decision, or all of these in parallel).

c. Artificial Intelligence

The fundamental building blocks of AI technology are knowledge representation, computer-based reasoning methods, and machine learning methods. These techniques and methods are used to implement three phases of problem solving: perception, cognition, and action. Intelligent agent architectures are frameworks that combine the three problem-solving areas into a system context. Within these technical areas, emphasis is on the development of new intelligent functionality and the engineering issues of integration, verification, validation, real-time performance, and life cycle maintenance.

There is a very close and active relationship between AI technology and the other software technology subareas, particularly software and systems engineering. The use of explicit knowledge, often acquired from human experts, and the ability to emulate human reasoning with AI problem-solving strategies have made this technology particularly attractive as an aid in decision making and as a substitute for, and augmentation of, human expertise. In addition, as AI technologies have moved into standard practice and become embedded within military systems, emphasis has shifted to include application issues such as scalability, the development of general purpose AI frameworks supporting the integration and reuse of AI with non-AI software components, validation and verification, real-time AI performance, and the life cycle maintenance and support of AI-based software products and their contents. Current DoD efforts in AI are focused on the invention of powerful new functionality, the maturing of AI technology and its insertion into and integration with conventional software environments, and the insertion of AI technology into conventional software engineering and the general software process.

d. Software for Parallel and Heterogeneous Distributed Systems

Future information processing systems will integrate multiple, concurrently operating computation elements into a seamless computing environment via robust local and wide-area networks. These systems will have the potential for orders of magnitude increase in throughput, with corresponding increases in survivability and availability, all of which are critical to DoD applications.

Significant and probably sufficient programs are ongoing and emerging in government and industry to develop the hardware technology necessary to support needed DoD capabilities. The corresponding programs to develop the appropriate software and communication technology are not as robust, and there remains considerable work to be done. DoD efforts in the operating system area (in addition to operating systems for high performance computers) span the range from basic research on the mechanisms for providing interoperability, resource management, fault tolerance, etc., to the development of advanced prototypes for evaluation testing with DoD users.

Several efforts in distributed data bases are investigating replication data bases as a vehicle for reliability, while other efforts are being directed at the establishment and maintenance of partitioned data bases to extend a common data model across multiple machines. Efforts in software development tools include those for distributed systems design, implementation, and testing; system application methodologies; software performance analysis; software testing; and concurrent languages. Finally, efforts in algorithms, which are primarily designed to upgrade basic mathematical libraries for new architectures, include the demonstration and validation of prototypes of sophisticated models and development of a much broader range of algorithms to capitalize on these new architectures.

e. Real-Time/Fault-Tolerant Software

Current and future DoD operations depend on high performance, correctly functioning, real-time computer systems capable of withstanding severe stresses without failing catastrophically. The DoD is increasingly dependent on electronic and computer technology as force multipliers, and without reliable RT/FT technology, advanced weapon systems lose credibility and effectiveness. RT/FT software must meet complex timing constraints despite faults and failures.

Many of the issues encountered in the development of RT/FT software are identical to those arising in software and systems development in general and, specifically, in the development of parallel and heterogeneous distributed systems. The distinguishing attributes in the construction of RT/FT software are the needs to demonstrate high levels of availability, reliability, and timeliness. RT/FT technology is particularly important in the integration of complex systems in which a rich combination of software modules, message types, processors, and communication media are shared. Overall, the technology for real-time software is immature for large complex systems. The results that exist may be distributed among four areas: specification and verification, scheduling theory and resource allocation, operating systems and programming data languages, and hardware architectures. The technology for fault-tolerant software, which is also immature, is distributed among fault detection, fault diagnosis, fault recovery, fault avoidance, and measurement. Current DoD efforts in this area include distribution tools to support robust system development, as well as real-time distributed systems; formal models of real-time systems and real-time scheduling theory; a fault-tolerant data base management system; a reconfigurable multicluster system; avionics fault-tolerant software; and prototype software for a real-time/fault-tolerant space-based signal processor.

f. High Assurance Software

High assurance is required for software that implements critical requirements representing specific characteristics whose absence or diminished presence can cause serious consequences in the operation of a system. Critical properties can be related to safety, security, performance, or other system attributes. Assurance is obtained when visibility into the design, development, and implementation is sufficient to verify that the critical requirements have been satisfied. DoD programs are currently addressing the following key elements of high assurance software:

(1) Identification and quantification of critical properties (including risk modeling and analysis, tradeoff methodologies for critical properties, and metrics for assurance).

(2) Foundations for high assurance (including formal models of critical properties, composability of models, formal specification languages, formal reasoning techniques, and programming language semantics).

(3) Tools for high assurance (software engineering environments with highly integrated tools that implement strong configuration management and support a range of formal languages and analysis tools).

(4) Certification (criteria used to measure the degree to which a system should be trusted to enforce a specific policy or property).

(5) Trusted and high assurance products related to security (products that meet trust classes defined by the Trusted Computer System Evaluation Criteria and products that meet more general criteria for other high assurance requirements).

B. TECHNOLOGY AREA GOALS

Table 2-1. Software Technology Area Goals*

Subarea	By 1995	By 2000	By 2005
Software and Systems Engineering	• Demonstrated 20% net savings through product and process metrics and assessments. • Demonstration of 40% reduction in software product errors via software engineering environments and improved, interoperable computer-aided software engineering (CASE) tools.	• Demonstrated 50-80% savings in narrow domains through reuse, domain/specific architectures, and reusable component certification. • Demonstrated savings up to 30% on some legacy software through re-engineering technology. • Time from system concept to fielding cut 25-50% in narrow domains.	• Demonstrated 40-60% savings in broad domains through reuse, domain architectures, and knowledge-based assistance. • Demonstration of 90% reduction in software product errors. • Demonstrated savings up to 60% on some legacy software through knowledge-based reengineering. • Time from system concept to fielding cut 25-50% in broad domains.
Human Computer Interaction	• Capability for natural language implementations. • 30% faster prototyping via model-based HCI. • Develop key HCI functions three times faster. • Formal specification techniques produce effective interface design reducing iterative cycles.	• Development of scalable multimedia systems. • Develop key HCI functions five times faster. • 50% faster HCI prototyping; technology insertion 30% less rework.	• 70% faster HCI prototyping with new media capabilities. • Development of more robust, fault-tolerant systems. • HCI development environment produces significant improvement in system development process.
Artificial Intelligence	• 8:1 increase in deployment planning efficiency. • 50% increase in vision accuracy via model-based reasoning. • Object-oriented modeling environments yielding up to 50% improvements in battlefield simulation development time.	• HPCC integration speeds some AI processing by 2 orders of magnitude. • Integrated planning and control permit tenfold increase in replanning timeliness. • Associate systems applications yield 2:1 performance improvements.	• Integrated artificial intelligence/operations research/decision theory frameworks provide 5:1 increase in utility of designs. • Applications compiled from functional specifications cuts development cost/time by factor of 5 in narrow domains.

*These milestones relate to research demonstrations of the impact of new technologies. Significant improvements in practice will also require concomitant improvements in related areas.

(Continued)

Table 2-1. (Continued)

Subarea	By 1995	By 2000	By 2005
Parallel and Heterogeneous Distributed Systems	• Reduction in data base cost by 20% through common repository standards.	• Near real-time heterogeneous distributed computing environments. • Development of common interface to DoD distributed systems.	• Strategic DoD data bases on-line and integrated. • Dynamic reconfiguration based upon intelligent agents. • Real-time heterogeneous distributed computing environments.
Real-Time/Fault-Tolerant Software (RT/FT)	• RT data base management system (DBMS) for embedded applications. • Demonstration of robust design as alternative to replication.	• RT heterogeneous DBMS. • Demonstration of RT software engineering design process. • RT AI for embedded applications.	• RT/FT megaprogramming engineering process. • RT/FT AI engineering process.
High Assurance Software	• Trusted local area networks (LANs). • Trusted distributed operating systems.	• High speed, long haul trusted networks. • Development methods for high assurance applications.	• Real-time trusted distributed operating systems. • Tools for high assurance applications.

C. RELATIONSHIP OF TECHNOLOGY GOALS TO THRUSTS

Table 2-2. Relationship of Software Technology Goals to Thrusts

Subarea / Thrust	Software and Systems Engineering	Human Computer Interaction	Artificial Intelligence
1. Global Surveillance and Communications	• 20-80% reduction in system software costs. • 25-75% reduction in fielding time for major systems. • 40-70% reduction in software error rates. • Support for common architectures. • Support for evolutionary development and reengineering	• Hypermedia. • Better speech communication. • Use of intelligent adapter user interfaces. • Safe HCI.	• Improved analysis of large amounts of data. • Improved high performance computing integration. • Development of image understanding techniques for imagery dissemination.
2. Precision Strike	• See Row 1 above.	• Hypermedia. • Better speech communication. • Use of intelligent adapter user interfaces. • Safe HCI.	• Rapid strike: critical target location and rapid strike plan assembly. • Development of intelligent agent architectures.
3. Air Superiority and Defense	• See Row 1 above	• Hypermedia. • Better speech communication. • Use of intelligent adapter user interfaces. • Safe HCI.	• Development of real-time command and control for area air defense. • Development of large, reusable knowledge bases
4. Sea Control and Undersea Superiority	• See Row 1 above.	• Hypermedia. • Better speech communication. • Use of intelligent adapter user interfaces. • Safe HCI.	• Improved spatial and temporal reasoning for ocean surveillance • Qualitative simulation.
5. Advanced Land Combat	• See Row 1 above.	• Hypermedia. • Better speech communication. • Use of intelligent adapter user interfaces. • Safe HCI.	• Intelligent unmanned ground vehicles (UGVs) for mine detection and reconnaissance. • Development of intelligent Agent Architectures
6. Synthetic Environments	• See Row 1 above.	• Virtual reality capabilities. • Faster prototyping.	• Decision support systems for the Chairman, JCS, and Joint Staff. • Intelligent plan visualization and trade-off analysis workstations. • Integrated crisis action planning tools and military wargames
7. Technology for Affordability	• See Row 1 above • Infrastructure for affordable, reliable, adaptable process and supporting	• Computer supported cooperative work. • Faster prototyping. • Design support systems.	• Acquisition manager's associate system. • DoD national engineering information network • Improved acquisition technology and simulation.

(Continued)

Table 2-2. (Continued)

Subarea / Thrust	Parallel and Heterogeneous Distributed Systems	Real-Time Fault-Tolerant Software	High Assurance Software
1. Global Surveillance and Communications	• Seamless information environment from sensor to decision maker to fighter. • Location transparent access to and manipulation of multimedia data. • Interoperability among multi-Service elements.	• Survivable communications and computing. • Real-time information management. • Real-time decision support.	• Secure wide area, high speed communication. • Secure distributed processing. • Secure information management
2. Precision Strike	• Near real-time support for distributed planning and replanning. • Dynamic connectivity between planners and execution elements. • Interoperability among multi-Service elements.	• Dependable real-time communications and computing. • Real-time data fusion. • Real-time AI. • Real-time HCI.	• Safe, secure communication and computation. • Safe, secure AI. • Safe, secure HCI.
3. Air Superiority and Defense	• Near real-time support for distributed planning and replanning. • Dynamic connectivity between planners and execution elements. • Interoperability among multi-Service elements.	• Dependable real-time communications and computing. • Real-time data fusion. • Real-time AI. • Real-time HCI.	• Safe, secure communication and computation. • Safe, secure AI. • Safe, secure HCI.
4. Sea Control and Undersea Superiority	• Distributed, survivable platform information processing.	• Dependable real-time communications and computing. • Real-time data fusion. • Real-time AI. • Real-time HCI.	• Safe, secure communication and computation. • Safe, secure AI. • Safe, secure HCI.
5. Advanced Land Combat	• Seamless information environment from sensor to decision maker to fighter. • Location transparent access to and manipulation of multimedia data.	• Dependable real-time communications and computing. • Real-time data fusion. • Real-time AI. • Real-time HCI.	• Safe, secure communication and computation. • Safe, secure AI. • Safe, secure HCI.
6. Synthetic Environments	• Information handling back for distributed simulation capability.	• Real-time simulation.	• Secure wide area, high speed communication. • Secure HCI.
7. Technology for Affordability	Information handling backbone for distributed software engineering environments.	• Dependable information management in large-scale, heterogeneous computing environments.	• Secure wide area, high speed communication. • Secure distributed processing. • Secure information management

D. SUBAREA ROADMAPS TO REACH TECHNOLOGY GOALS

Table 2-3. Roadmap of Technology Objectives for Software and Systems Engineering

Technology Set	By 1995	By 2000	By 2005
Process Management Support	• Process model elements for requirements/reuse/prototyping/Ada. • Risk assessment techniques. • Advanced process maturity assessments. • Acquisition maturity assessment. • Core metrics data repository.	• Process and product metrics and estimation models. • Iterative process models. • Risk analysis tools. • Full-service metrics data repository.	• Metrics, estimation techniques for iterative process models. • Advanced Post-Deployment Software Support (PDSS) process models. • Sizing, attribute metrics.
Software/ Systems Tools and Environments	• Paradigms of CASE interoperability across vendors and throughout life cycle. • Hypermedia software engineering environment (SEE) front ends integrating multiple tools. • Verification/validation tools incorporating limited semantic analysis. • Limited commercial acceptance of open architecture SEE framework.	• Open architecture SEE framework with process support. • Interactive requirements elicitation with prototyping to support early validation.	• Interface and architecture codification and validation. • Tools for support simulation and prototyping for position of hardware/ software interfaces in systems. • Preliminary verification/ validation tools supporting hybrid testing, analysis and formal methods.
Reuse and Reengineering	• Process support for reuse. • Cost benefit data base for reuse, reengineering. • Initial repository technology with basic security, search, categories. • Initial reuse via domain-specific architectures and interfaces.	• Cost/benefit/risk analysis for reuse, reengineering. • Initial design record recovery technology for mission-critical systems. • Repository supporting distribution, security, replication.	• Full interface specification module interface formalism codification of systems software components. • Domain-specific tooling (very high level language, optimization, program generation). • Design record recovery technology for mission-critical systems integrated into SEE framework/tools
Information Engineering	• Extensive AI planning and decision support. • Business-case modeling and performance metrics. • Data model management (meta-data) aids. • Access to disparate data models (remote data base access). • Limited Ada bindings for specific domains. • Initial collaborative decision making.	• Robust data modeling tools/methodologies. • Domain-specific data models. • Data base integration. • Scalable object-oriented DBMS and information models.	• Reconfigurable hybrid networks. • Deductive/semantic DBMS with decision support • Information systems tailorability (domain support). • Integration of security into standards. • Data search and retrieval with incomplete data.

Table 2-4. Roadmap of Technology Objectives for Human-Computer Interaction

Technology Set	By 1995	By 2000	By 2005
Dialog Modeling/ Management	• Prototype dialogues for specific domain using hypermedia, speech communication and virtual reality.	• Ad hoc hypermedia, speech communication, and virtual reality design supplanted with principled design.	• Hypermedia, speech communication, and virtual reality dialogue implemented in operational systems.
Specification Methods	• HCI interface development supported by specification techniques.	• Interface specification techniques integrated with application development and scaled to real systems.	• Specification techniques support development of complex systems.
Software Tools	• Model-based human-computer interaction development tools prototyped.	• Software support for hypermedia, speech communication, and virtual reality design added to development environment.	• Human-computer interaction software tools support operational system development.

Table 2-5. Roadmap of Technology Objectives for Artificial Intelligence

Technology Set	By 1995	By 2000	By 2005
AI Technology Base	• Custom tool kits for vision, planning, speech. • Standardized knowledge representation languages and services. • Basic knowledge base management aids.	• Standards, reusable modules of machine learning methods.	• Libraries of reusable knowledge. • Integrated AI/OR/DT frameworks.
Intelligent Systems/ Thrust Area Prototypes	• Standards for integration AI and convention software. • Initial knowledge representation standards. • Transition via shared testbeds.	• Integrated data bases and knowledge bases. • Libraries of reusable AI methods. • Applications tailored and extended by users.	• Intellig [illegible] mentation. • Integra [illegible] transition via simula [illegible] worlds. • Reusable knowledge services. • Intelligent support for technology assessment. • AI systems built by software people assisted by intelligent AI agents.

Table 2-6. Roadmap of Technology Objectives for Parallel and Heterogeneous Distributed Systems

Technology Set	By 1995	By 2000	2005
Operating Systems		• Heterogeneous distributed operating system services: static, loosely coupled (limited capability).	• Heterogeneous operating system services, variety of coupling. • Dynamic resource allocation for load balancing and survivability.
Database and File Systems	• Manual, prearranged data compatibility across heterogeneous components.	• Retention of data integrity/significance. • Distributed data base (DB) services, heterogeneous DBs (limited capability). • Static archive allocation.	• Parallel and distributed transparent DB exchange. • Archive optimization. (limited automation) • Massively parallel DB. • Distributed DB services of homogeneous model. • Multimedia access, services.
Development Tools	• Massively parallel Ada.	• Formal specifications and partitioning across heterogeneous processors. • System modeling/ simulation (limited capability). • Test stimulators across heterogeneous processors (limited capability).	• Formal specification, RT considerations. • Language interoperability. • Test simulations/validation across heterogeneous components. • Test tool set for hybrid systems. • System toolset for hybrid systems.
Application Algorithms	• Massively parallel sensor processing (variable capability). • Limited math/data and application algorithms.	• Macro building capability (limited capability). • Scalable math/data (robust), application (limited).	• Massively parallel algorithms. • Macro building capability.

Table 2-7. Roadmap of Technology Objectives for Real-Time/Fault-Tolerant Software

Technology Set	By 1995	By 2000	By 2005
Real-Time Software Technology	• Some limited capability "best effort" approaches to real-time scheduling. • Scheduling techniques for mixed workload (periodic and sporadic tasks) for uniprocessors. • Dynamic scheduling of tasks with dependencies for uniprocessors. • First generation real-time operating systems such as real-time Mach and Alpha. • Performance measurement and estimation for small-scale, real-time systems. • Automatic synthesis of hard real-time schedulers for uniprocessors.	• Automatic allocation of processes to processors for real-time systems. • Hardware-independent abstract functional and performance models.	• Optimality models for hard real-time parallel systems. • Specification and verification tools for robust adaptive systems. • Language and runtime support. • Global optimization of resource management (across processing, communication, and data) for real-time distributed systems.
Fault-Tolerant Software Technology	• Adaptive fault tolerance techniques for small-scale systems. • N-version programming. • Ability to instrument a limited set of fault tolerance metrics.	• Integrated real-time/fault-tolerant systems. • Some adaptive fault tolerance support for complex distributed systems. • Reliability estimation models • Distributed operating system support for transactions.	• Design tools for fault-tolerant system (hardware/software) design.

Table 2-8. Roadmap of Technology Objectives for High Assurance Software

Technology Set	By 1995	By 2000	By 2005
Identification & Quantification of Critical Properties	• Risk modeling for some domain-specific data confidentiality and safety properties.	• Risk modeling for availability and integrity.	• Preliminary results in critical properties tradeoff.
Foundations for High Assurance	• Composable homogeneous data confidentiality models. • Formal models of integrity properties. • Formal specification of integrity. • Formal specification languages. • Formal programming language semantics.	• Formal models of safety and availability.	• Formal models of other security properties. • Formal reasoning systems.
Tools for High Assurance	• Spiral model for high assurance software. • Verification tools for Ada. • Formal specification support tools. • Additional confidentiality proofs. • Modeling environment for data confidentiality.	• Languages with formal semantics. • Formal specification languages.	N/A.
Certification Methodologies	• Evaluation criteria for security properties of some network components.	• Confidentiality evaluation criteria for system components.	• Certification criteria for security. • Certification criteria for other critical properties.
Trusted and High Assurance Products	• A1-based intrusion detection. • Trusted LANs up to class A1. • Privacy enhanced mail. • Trusted parallel and heterogeneous distributed operating systems. • Class A1 data base management systems (DBMS). • Privacy enhanced mail.	• High assurance, high performance DBMS. • Trusted distributed operating systems. • Software encryption. • High assurance workstations. • High speed long haul trusted networks.	• Trusted multimedia DBMS and trusted workstations. • Real-time trusted distributed operating systems.

N/A = Not Applicable.

E. R&D IN OTHER ORGANIZATIONS (GOVERNMENT, INDUSTRY, FOREIGN)

1. Government

Many agencies have efforts in one or more of the software technology subareas. The National Science Foundation (NSF) sponsors basic research in software technology, with an emphasis on smaller scale projects, though there are several larger centers sponsored by NSF that engage in experimental research. Although moderate-scale prototype engineering activity is now undertaken more frequently, most NSF support is provided to individual researchers. Efforts in human-computer interaction are being conducted at the Department of Transportation and the National Institutes of Health (NIH) for the handicapped. NIH is also conducting research in large-scale scientific data bases and in parallel algorithms that are applicable to the health sciences. The Department of Energy conducts research in human-computer interaction and real-time/fault tolerant software.

Several agencies, including FAA and NASA, have Ada-related activities. NASA is utilizing Ada on the Space Station Freedom Program and is sponsoring a major Ada-based software engineering environment. NASA sponsors a significant range of software efforts that bear on DoD goals, such as real-time, fault-tolerance, high assurance, software metrics, and software life-cycle support. Similarly, FAA sponsors efforts in human-computer interaction and real-time/fault-tolerance.

NIST conducts research focused on high integrity software by developing technologies that address software assurance and quality. Research includes formal methods for specification and verification, as well as quality assurance techniques based on testing and statistical methods. NIST is also developing the SDIO Software Manufacturing Operations Development Integration Lab (MODIL) with an initial thrust in software reuse.

2. Industry

Although there are DoD-specific software technology requirements, particularly in security and real-time systems, the DoD generally benefits by exploiting commercial capabilities. The DoD is able to benefit not only through the sharing of product development and enhancement costs with all other customers, but also through greater product cost-effectiveness, robustness, and reliability that result from competitive pressures. In domains such as information systems, where DoD requirements to support payroll and other routine operations are similar to requirements in other sectors, most DoD needs can be met through commercial products with occasional customization. In situations where commercial products cannot be exploited, the DoD can often still benefit from use of commercial standards such as those in communications, data interchange, and systems software interfaces.

The commercial industrial base also provides a wide range of software tools, although effective multivendor integration of these tools remains lacking (a current area of DoD R&D focus). Tools available include Ada compilers, associated support tools, and many computer-aided software engineering (CASE) tools. Many of these tools were originally developed for use in the much larger business and manufacturing systems integration market. The DoD, through its efforts in software engineering environment frameworks, is seeking high levels of compatibility with these tools.

DoD also exploits scientific/engineering software packages that emerge from the commercial sector. However, there are many DoD-specific requirements in all areas, and the extent to which DoD requirements will lead the market in this area will likely increase. For this reason, DoD R&D investment continues to address both immediate DoD needs and longer term generic technology needs where DoD will likely have special requirements. This investment has yielded, and continues to yield, significant impact in ensuring that DoD requirements can be effectively addressed.

Based in part on prior DoD investment, there are several potential areas of increased industrial capability that can be envisioned. These areas include software environments and tools (where environment frameworks will emerge to support multivendor tool integration, direct process support, and consistent user interface management); advances in operating systems (to enable a higher degree of integration of diverse application software on advanced workstations); and potential generic kernel support for real-time and fault-tolerant systems.

The continued DoD R&D investment strategy will yield a stream of commercial advances that will address a wide range of DoD needs. Those requirements, however, that are highly DoD specific, can often be addressed by using hybrid system approaches, involving the use of domain-specific software architectures populated by both commercial and DoD-developed components. These hybrid systems can continue to be used to exploit growth in capability of the commercial components as well as the concomitant growth in computational power of the underlying computing systems base.

3. Foreign

The European and Japanese communities are developing partnerships among government, industry, and academia at a much faster pace than the United States. At this point, however, no single country is competent in as many technologies as the United States, and the research into software technology in the United States is probably better than research in Japan and Europe. Opportunities for cooperation with Europe and Japan include niche areas associated primarily with supercomputing, specialized methods for exploiting massively parallel architectures, and formal methods for highly reliable and portable software.

Software development has been an area of major emphasis in European funding programs. Multinational ventures in Europe have the potential for achieving comparability with the United States by combining individual strengths. Large-scale European projects are sponsored by the European Strategic Program for Research in Information Technology (ESPRIT) and European Research Coordination Agency (EUREKA), using joint industrial and government funding. Total funding in information technology is more than 500 million European Currency Units (ECUs) per year. Technological areas being addressed that are of particular interest to software technology include formal methods, process-driven environments, environment framework technology, natural language processing, and common standard interfaces for software environments.

The EUREKA program promotes collaboration through coordination. Two of the key EUREKA programs are EUREKA Advanced Software Technology (EAST) and European Software Factory (ESF). Explicit emphasis is given in ESPRIT to the development of common software interfaces and portable tools. Another key program is the European Software and System Initiative (ESSI). ESSI is aimed at increasing software productivity. Additional emphasis on the use of formal methods to develop highly reliable software has led to a European lead in some areas.

In addition to ESPRIT and EUREKA, individual European countries have their own programs. The U.K. is developing software engineering tools and is also conducting parallel language work. France and Germany also have extensive efforts addressing a wide range of software engineering topics, including algorithms and software for parallel architectures, and software engineering environments and tools.

In Japan there are three areas of particular interest: natural language processing, distribution and process management, and distributed access to tools. The Japanese have emphasized management of the software development process and initiatives to support reuse in specific applications areas, commonly known as the Japanese "software factory." The Japanese Ministry of International Trade and Industry recently implemented several programs specifically designed to improve Japanese capabilities to produce software and expand production capacity.

Japanese companies are developing an operating system for distributed real-time processing for their new generation of 32- and 64-bit microprocessors. Software to support massively parallel processing systems is also an area of major emphasis. The Japanese have developed strong programs and devoted considerable resources to develop and improve Fuzzy logic software and continue neural net R&D.

Outside of Europe and Japan, virtually all industrialized nations have some efforts relating to the development of specific algorithms, including research into optimizing the performance of such algorithms on parallel machines. The nature of this research lends itself to individual breakthroughs in specific algorithms. These may contribute to significant advances beyond existing U.S. capabilities but cannot be predicted or planned for in advance. Capabilities in the Commonwealth of Independent States (CIS) and China merit special attention.

Prior to its dissolution, the USSR demonstrated strong theoretical capabilities in computer science. Soviet researchers had mastered numerous theoretical techniques for the automated production of software. The Soviet computer science community had also developed a strong capability to produce software for highly parallel computers. Today, the CIS continues to capitalize on the traditional Soviet strength in mathematics for algorithm development, and institutes and plants supporting military R&D and production are still likely to be the first to assimilate any new software techniques.

Software technology continues to be an area of serious deficiency for the CIS, however, largely because of a shortage of computers, especially microcomputers and supercomputers. CIS programmers lack adequate hands-on computer experience. Computer-to-computer networking is rare except in high priority applications. The situation is exacerbated by the poor quality of public telecommunications and poor technical communications among S&T professionals. The issue of computer security has become as important to the CIS as it has to the United States. It is highly unlikely, though, that CIS computer security is any better than that of the United States.

Recent Chinese work has focused on establishing a viable software industry with strong capabilities in the microcomputer and workstation arenas. China has developed a strong cadre of software programmers and is making gains in expertise, as well as the acquisition of advanced equipment, through joint ventures with the U.S., Japan, and other nations. China's eighth 5-year plan emphasizes software for CAD/CAM and information management.

Table 2-9. Summary and Comparison — Software

Subarea	NATO Allies	Japan	CIS	Others
1. Software and Systems Engineering	□□□□ O	□□□□ O	□□	□□ Including India, Israel, Sweden, and Hungary
2. Human-Computer Interaction	□□□ O	□□□ +	□	□
3. Artificial Intelligence	□□□ –	□□□ O	□□	□□ Including China, Israel, S. Korea, and Former Yugoslavia
4. Software for Parallel and Heterogeneous Systems	□□□ O	□□□ O	□□	□□ Including China, India, and S. Africa
5. Real-Time/Fault-Tolerant Software	□□	□□	□	□
6. High Assurance Software	□□	□□	□	□
Overall[a]	□□□ O	□□□ O	□	□□

[a] The overall evaluation is a subjective assessment of the average standing of the technology in the nation (or nations) considered.

LEGEND:

Position of other countries relative to the United States:

- □□□□ Broad technical achievement; capable of major contributions
- □□□ Moderate technical capability; possible leadership in some technical niches; capable of important contributions
- □□ Generally lagging; may be capable of contributing in selected areas
- □ Lagging in all important aspects; unlikely to contribute prior to 2002

Trend indicators—where significant or important capabilities exist (i.e., 3 or 4 blocks):

- \+ Foreign capability increasing at a faster rate than the United States
- O Foreign capability increasing at a similar rate to the United States
- – Foreign capability increasing at a slower rate than the United States
- ? Currently unable to assess rate of change in foreign capability vs. the United States

F. FUNDING

Table 2-10. Funding by Software Subareas
($ in Millions)

Subarea	FY92	FY93	FY94
Software and Systems Engineering	79	79	77
Human Computer Interaction	7	7	7
Artificial Intelligence	60	56	53
Parallel and Heterogeneous Distributed Systems	36	36	32
Real-Time/Fault-Tolerant Software	6	6	6
High Assurance Software	20	18	18
TOTAL	208	202	193

Table 2-11. Funding by Program Element
($ in Millions)

PE No.	Title	FY92	FY93	FY94
0601101E	Defense Research Sciences	20.0	28.0	20.0
0601102A	Defense Research Sciences	1.0	1.0	1.2
0601102F	Defense Research Sciences	5.9	8.0	10.0
0601152N	In-House Independent Laboratory Research	0.4	0.5	0.5
0601153N	Defense Research Sciences	11.4	13.7	12.6
0602201F	Aerospace Flight Dynamics	0.1	0.1	0.1
0602202F	Human Systems Technology	1.3	1.3	1.3
0602204F	Aerospace Avionics	1.1	1.1	1.0
0602211A	Aviation Technology	0.2	0.2	0.2
0602234N	Systems Support Technology	11.0	11.5	11.5
0602301E	Strategic Technology	50.0	91.0	90.0
0602303A	Missile Technology	0.1	0.1	0.1
0602702F	Command, Control, and Communications	4.8	6.4	6.8
0602708E	Integrated Command and Control Technology	5.0	0.0	0.0
0602783A	Computer and Software Technology	4.5	6.6	6.5
0602785A	Manpower/Personnel/Training Technology	0.2	0.2	0.2
0602789A	Army Artificial Intelligence Technology	3.4	3.3	3.3
0603007A	Human Factors/Personnel/Training Advance	0.4	0.5	0.5
0603215C	Limited Defense System	7.5	7.7	8.8
0603728F	Advanced Computer Technology	9.8	11.1	9.9
0603756D	Consolidated DoD Software Initiative	26.5	9.0	7.8
0603756E*	Consolidated DoD Software Initiative	42.3	0.0	0.0
0603772A	Advanced Tactical Computer Science and Technology	1.0	1.0	1.0
	TOTAL	207.9	202.3	193.3

*This Program Element is consolidated with PE 0602301E starting in FY93.

3. SENSORS

A. DESCRIPTION OF TECHNOLOGY AREA

1. Scope

Sensor technology focuses on developing and applying fundamental principles and devices for sensor systems using radar sensors, electro-optics (EO) sensors, acoustics, and multisensor integration. Radar technologies include monostatic and multistatic radar techniques using various waveforms for coherent and non-coherent signal processing. EO technologies include passive and active sensing for infrared (IR) search and track, forward-looking IR (FLIR), visible sensing and displays, and signal processing. Radar technologies provide for the capability to search, acquire, identify, and track targets in air, land, and surface environments. EO technologies complement those of radar technologies. Acoustics includes passive and active sensors for underwater objects location/identification and battlefield non-line-of-sight detection (alerting), localization, tracking, and positive-hostile ID of ground combat vehicles. Multi-sensor integration is a combination of information from more than one sensor to provide a composite of the environment and to perform target extractions which would not be possible with a single sensor.

2. Sensor Technology Subareas

a. Radar Sensor Technology

This sensor utilizes ultra/very high frequency (UHF/VHF), microwave, and millimeter wave technologies for search, detection, acquisition, identification, and track of airborne, spaceborne, and surface targets (friendly and hostile) over large spatial envelopes in complex environments of clutter, countermeasures, and advanced target signature suppression. This technology is subdivided into two sub-subareas: monostatic and multistatic radar. Radar sensor technology is dictated by specific operational employment environments, platforms, and informational utilities. Principally, Radar sensors are employed for global (space-based) surveillance, airborne wide area surveillance, surface-to-surface/surface-to-air, and air-to-air/air-to-surface mission areas.

b. Electro-Optic Sensor Technology

Electro-optic technology provides EO/IR techniques, components, and systems to enhance military capabilities for target detection, surveillance, tracking, classification, and identification. This technology is divided into two major subareas: Passive ("silent") sensors such as thermal imagers (commonly called FLIR), low light level TV, infrared search and track systems (IRST); and active sensors which emit radiation such as laser systems and illuminated FLIRs. Both passive and active EO sensors are operational employment and target dependent. Operations in reduced visibility created by weather conditions, smoke, dust, and optical countermeasures impose technology requirements for high sensitivity, high resolution sensors employing multispectral, and multielement detectors and optics. Heavy emphasis is placed on EO sensors for point defense and the horizon detection of anti-shipping, sea skimming missiles. Space-based EO sensors are required for missile launch detection, tracking, and weapon cueing.

c. Acoustics

Acoustics include passive and active sensors for undersea and battlefield operations. For the undersea acoustics, passive and active sensors are used for anti-submarine (ASW) and mine detection. Battlefield acoustics are passive sensors used for intelligence gathering and remote sensing for mine initiation.

d. Multisensor Integration

This key technology focuses on data from one or more sensors to perform long-range detection and tracking, noncooperative target recognition (NCTR), or automatic target recognition (ATR). Multisensors use several sensors which operate at different frequencies and are coordinated and integrated to increase the accuracy and credibility of the data prior to utilization for NCTR and weapon delivery.

3. Assessment

a. Radar Sensors

Monostatic Radar Sensors. Monostatic technology is the fundamental, traditional radar for air, surface, and space radar applications. This technology is directed at both coherent and non-coherent transmit/receive functions using pulsed continuous wave (CW) and more complex waveforms. Conventional monostatic radar technology is presently the sensor used against the reduced observable threat, and it may not be adequate in many scenarios. Radar cross section is inversely frequency dependent and is most difficult to suppress at relatively low frequency. Radar using a relatively low frequency uses a broad fractional bandwidth to maintain good range resolution and rejection of clutter. A radar using a wider frequency spectrum is more likely to employ the frequency at which the radar return is greatest but is restricted by operational employment and platform (surface, airborne or spaceborne) considerations. Key technologies for surface-based application focus on size/weight, stabilization requirements, power levels, detection/classification, and survivability against the anti-radiation missiles (ARM). Detection of low cross section targets concealed in and behind foliage imposes needs for special waveforms and processing algorithms. In addition, these systems provide navigation and targeting capability. Supporting technologies such as advanced signal processing, high resolution, data fusion, and ARM survivability are critical to the air intercept mission. Monostatic airborne sensor radars include: airborne intercept, airborne anti-surface warfare (ASUW), strike, and ASW radars. Airborne intercept radar technology developments stress improved detection at extended ranges, including inbound missile warning, counter-ARM techniques, and air target identification. ASUW radars emphasize recognition techniques that apply inverse synthetic aperture radar (ISAR) technology to produce images in two dimensions of ship targets, suppress clutter, and generate recognizable target signatures and Battle Damage Assessment (BDA) data. Strike radars focus on air-to-surface weapons delivery against an assortment of mobile and stationary tactical targets in heavily defended, heavily countermeasured environments. Multiple aperture, multiband radar techniques allow integrated radar and Electronic Warfare (EW) functions. Designs which minimize radar cross section when installed on host aircraft are emphasized. Airborne ASW radar is uniquely linked to the Navy requirements to detect and attack submarine targets. The technology addresses periscope and wake detection techniques; requires systems that utilize special transmission waveforms, low observable emissions, clutter processing techniques, and wide area coverage; and incorporates design approaches for fixed- and rotary-wing aircraft that are both land and carrier based. The key technologies which offer potential high-payoff are the Phased Array, Over the Horizon (OTH), SAR, and ISAR.

Multistatic Radar Sensors. Multistatic radar is the emerging predominant sensor technology for many surveillance functions and operations. It compr... es four major subareas which are scenario/platform/target set driven. Bistatic, Phased Array, and OTH are grouped into this subarea. In [illegible]tic radar, the transmitter and receiver are separated by a significant distance, and they may provide additional capability to counter low observables. Low radar cross section targets may deflect the radar wave with higher power at multistatic angles (forward scatter) than at the back scattered monostatic reflection. Technological issues include transmitter and receiver timing and maintaining the bistatic angle. Radar cross section reduction methods include shaping techniques to scatter the radar signal at angles other than the monostatic angle. A multistatic receiver under some geometric conditions could detect the target where a monostatic receiver might not. This separation technique provides the added benefit of passively engaging the target while actively illuminating it, as is the case with the Patriot missile or with simpler "semi-active" systems. In addition, close coordination of two radars can have additional benefit in locating a target in two coordinates with good range accuracy, as opposed to using the single bearing azimuth accuracy of monostatic radar. The following sensor technologies apply to both monostatic and multistatic radar techniques:

Phased Array Radar. Conformal phased array radars using thousands of transmit/receive modules incorporated into airframes (e.g., remotely piloted vehicles (RPVs) and long-duration aircraft), light satellites, ground vehicles, and ship hulls can reduce radar signatures, making our platforms more survivable. Also, scan patterns can be electronically randomized to deter countermeasures. In addition, due to the lack of mechanical parts, phased array radars provide increased reliability and flexibility over conventional reflector radars. Phased arrays can instantaneously dwell in a specified direction and can scan a full 360-degree sector, allowing quick adaptation to changing battlefield conditions and concentration on a specific target or area of high military interest. Large, ground-based solid state radars are to be used by SDIO in strategic and tactical ballistic missile defense.

Over-the-Horizon Radar. OTH radar technology focuses on a next generation Continental United States (CONUS) defense system using the unique phenomenon of the reflection of high frequency (HF) (3 to 30 MHz) radio waves from the ionosphere to extend radar coverage well beyond line-of-sight ranges, e.g., 2000 nautical miles. Distinctive problems dealing with ionospheric propagation, signal decorrelation, ionospheric clutter, and anomalies in HF band antenna performance are issues for OTH radar.

SAR/ISAR Radar Sensors. SAR/ISAR radar sensors are coherent imaging systems developed for specific target sets and operational platforms. Aerospace and surface-based platforms are used for the anti-aircraft warfare (AAW) and ASUW mission requirements. A SAR is a high range resolution radar on a moving platform. Platform motion is used to synthetically create a large, high resolution antenna aperture. An ISAR applies the same principles as SAR except that target motion is used to synthesize antenna aperture instead of host platform motion. Both SAR and ISAR use high resolution in range and high resolution doppler signals in cross range to form target images.

Space-based SAR radar technology is unique in that requirements focus on light weight, low maintenance, space environment-qualified designs that search enormous areas, adapt to significant background variations, and provide highly efficient use of the space-generated power. The tech base includes a number of antenna and transmitter designs including distributed arrays, space-fed lens, and low loss transmit/receive modules as well as space-based signal processing and automated testing techniques. Antenna main beam and sidelobe nulling techniques for jammer suppression and real-time algorithms/processing techniques are being developed.

Aerospace ASUW radar technology addresses the requirement for surface target detection, identification, and classification from a satellite or airborne platform radar using coherent ISAR. The primary emphasis is on ISAR "real-time" processing of the radar returns to extract signatures that can be correlated with a data base to provide valid ship target classification and identification in background clutter, electromagnetic interference (EMI), and electronic countermeasures (ECM) environments.

Wideband/Ultra-Wideband Radar. Conventional monostatic radar uses a colocated radio frequency transmitter and receiver operating in the microwave/millimeter wave spectral region with transmitted waveform modulation occupying a small fraction of the center transmitted frequency. Tunable and broadband high energy monostatic radar technology can detect advanced, low observable (LO) threats. Wideband/ultra-wideband radar (UWB), where the bandwidth is at least 50 percent of the center frequency, may help counter a reduction in threat radar cross section by addressing the frequency dependent trade-offs inherent in LO design.

b. Electro-Optics Sensors

Passive EO Sensors. Passive sensors (i.e., sensors that do not emit radiation in order to find targets, but instead merely receive emitted energy) are increasingly important to counter future enemy reductions in observable characteristics across many frequency bands. Passive sensors do not divulge information about the host platform which can be exploited by an enemy. Stealthy systems employ passive sensors to detect, track, and identify objects/targets while maintaining their own covertness. Subarea technologies include passive missile warning thermal imagers and IRST (point source detection) systems.

Passive threat warning technology provides strategic or tactical alert so that defensive measures may be taken. These systems include laser warning devices and warning of passive EO/IR guided missile threats. Passive receivers to detect hot missiles and plumes are crucial to maintain U.S. force survivability as smart missiles proliferate.

Missiles guided by passive hot spot IR seekers home on thermal energy emitted by the target. Imaging seekers using infrared focal plane arrays (IRFPAs) allow target identification, tracking, and optimal aimpoint determination. Higher resolution in a smaller volume is required to support advanced brilliant missile systems. Seeker cost reduction is vital to future weapon affordability.

Advanced thermal imagers use the IR spectral region for su[illegible] acquisition, identification, tracking, weapon guidance, and kill assessment. Thermal imagers are necessary for night operations and passive surveillance, but water vapor absorbs infrared energy, limiting thermal imaging through clouds. IRFPAs are critical components of most advanced passive IR sensors. Thermal imagers are either scanning with a rotating mirror focusing the received thermal energy on a narrow (e.g., 1 or 2 by n) detector array, or staring using a larger dimension array (e.g., 256 x 256). Ultra-large arrays (greater than 512 x 512) will be used to detect missile launch from space. Efficient cryocoolers and digital readout electronics are essential for thermal imagers' effectiveness on many platforms.

IRST technologies focus on surface and airborne system applications to compliment radar in an ECM/all-weather environment to acquire and track both high- and low-flying or sea-skimming point targets at long ranges. They are also used in endo- and exo-atmospheric interceptor seekers for missile defense. Technology for multicolor/ multispectrum IRST is emphasized to provide improved target detection and recognition.

Active EO Sensors. These systems are primarily laser radars (LADARs) and laser rangefinders and target designators. Coherent laser radars are optical wavelength analogues of microwave radars. They provide advantages of bandwidth, physical size reduction (e.g., in antennas), and higher resolution. In addition, laser radar is used for environmental sensing and for target recognition. Environmental effects can cause attenuation of the coherent laser radar beam and the manifestation of undesirable speckle patterns (arising from target roughness and atmospheric turbulence); this speckle is subject to control, to some extent, by optimum processing.

Laser radars (LADARs) provide a highly accurate tracking and weapon control capability. It can also provide an important NCTR capability through imaging and target/laser beam interaction phenomena, as well as target discrimination of ICBM re-entry vehicles. Helicopters can enhance their survivability by using LADAR for obstacle avoidance. Blue-green laser radars are used for rapid, shallow-water minefield mapping in support of amphibious operations. Laser radars are used for remote environmental monitoring, including chemical agent or persistent nuclear dust cloud detection.

c. Acoustics

Active Acoustics. Sonar for undersea surveillance and weapons fuzing technologies can detect, classify, localize, track, and kill or neutralize undersea targets in all environments. Active acoustics emphasizes technologies needed for operations in harsh, shallow water environments and for torpedo defense alerting technologies for both surface ships and submarines.

As submarines reduce their radiated noise and quiet diesel electric submarines proliferate throughout the world, more sensitive acoustic arrays become increasingly important to U.S. maritime strategy. Acoustic (and seismic) arrays are also being used for detection and identification of aircraft, ground vehicles, and troop movements; however, increased understanding of the propagation of acoustic signals continues to be needed for improved sensor performance prediction and acoustic path characterization. Active Acoustics provides sensors for Navy mines, mine countermeasures, special warfare, and explosive ordnance disposal equipment.

Passive Acoustics. Passive acoustics provide non-line-of-sight detection (alerting), classification, localization, tracking and positive-hostile identification of military targets including artillery, ground combat vehicles, and aircraft. Passive underwater acoustics have long been the primary sensor technology for ASW. The principal thrust in tactical passive acoustics is toward larger arrays to improve low frequency response and support multistatic active acoustic reception. Fiber-optic sensor technology will play a major role to reduce array cost, space, and weight and eliminate electronic array noise. The use of geophone and microphone array technology for acoustic detection of air and ground targets is being explored to address the environmental effects such as temperature inversions, wind, and terrain.

d. Multisensor Integration

NCTR technology using multiple sensors reduces fratricide and the inadvertent killing of noncombatants. Combinations of sensors are needed for battle management and for smart, beyond-visual-range weapons. Imaging techniques such as SAR and EO are used for detection and identification of camouflaged or foliage-concealed targets. SAR is also used for air- and space-based imaging of lower altitude and ground-based targets. ISAR is used for ship classification. Ultra-high range resolution radar will provide a significant aircraft identification capability. Millimeter wave radar imaging will be used in air defense, missile defense, and fire-and-forget missile seekers. Continued development of MMW radar technology is critical for the Army with its array of small diameter smart munitions and precision-guided munitions that impose severe form, fit, function, and cost restraints on the seeker/sensor design and production. Automatic target recognition radars provide target data needed by weapon system processors for target determination. The information from several of these systems is input, either automatically or through human assistance, to a fire control system or smart weapon.

B. TECHNOLOGY AREA GOALS

Table 3-1. Sensor Technology Goals

Subarea	By 1995	By 2000	By 2005
Radar Sensors	• Counter 1,000-fold reduction in threat observability. • Allow passive weapon systems to engage threat illuminated by remote source. • Counter 1,000-fold reduction monostatic radar cross section. • Active conformal arrays embedded on structures. • High power, narrow beam active apertures. • Light, small, power efficient radar for RPVs. • Combine transmit, receive, illuminate and communications functions.	• Improve resistance to countermeasures by 100%. • Continuous moving target indicator to keep track of all MTI vehicles. • Provide capability to detect, track, and engage advanced threats including stealthy cruise missiles and aircraft. • Improve operational performance in severe environments. • Reduce own platform radar cross section. • Deployment of radars on light satellites, RPVs, etc. • All aspect target ID.	• Low probability of intercept multistatic radar. • Multifunction/multi-mission radar. • Adaptive conformal arrays. • Multiaperture antennas. • Affordable radar for UAV, MTI, and SAR missions. • Combat ID.
Electro-Optical Sensors	• Accurate target tracking, identification, and weapon guidance. • Detect and identify camouflaged or foliaged-concealed targets. • Rapid minefield mapping. • Real-time environmental monitoring. • Demonstrate integrated detector array, electronics, and dewars in standard assembly. • Demonstrate high density uncooled FPA. • Develop space qualified 5-year reliable cryo-cooler.	• Provide capability to detect, track, and engage stealthy cruise missiles and aircraft in severe clutter. • Improve survivability by 100%. • Enhance weapon lethality. • Provide remote, real-time detection of chemical agents. • Demonstrate large-scale multiple color staring FPAs. • Demonstrate miniature low cost, integrated detector/dewar assemblies. • Target ID.	• Produce LWIR FPAs using conventional refrigerants instead of cryogenic cooling, reducing cost by 100%. • Protection against high-power lasers. • Demonstrate multi-spectral FPAs (scanning and staring). • Expendable high-performance BDA sensors for UAVs. • Combat ID.

(Continued)

Table 3-1. (Continued)

Subarea	By 1995	By 2000	By 2005
Acoustics	• Demonstrate multiple line tactical towed arrays. • Demonstrate fiber optic underwater planar array. • Demonstrate acoustic and seismic sensor array networks for low observable (−30 db) detection and tracking.	• Demonstrate shallow water deployable fiber optic arrays. • Develop network of remote acoustic and seismic sensors. • Demonstrate shallow water active classification for low frequency active sonar.	• Demonstrate integrated air and surface ship ASW with all sensor fusion and cueing.
Multi-Sensor Integration	• Integrate RF, EO, and ESM sensors for target acquisition increase and false alarm mitigation. • Integrate FLIR and laser rangefinder. • Evaluate multispectral electro-optic sensors. • Combine staring thermal imagers for NCTR and ATR with millimeter radar.	• Integrate multiple color IR, ladar, RF, and passive microwave sensors. • Multisensor data fusion to support NCTR.	• Develop flexible, shared aperture, integrated active/ passive sensor suites covering RF, visual, and IR spectral regions. • Multisensor correlation and fusion for accurate combat ID.

C. RELATIONSHIP OF TECHNOLOGY GOALS TO THRUSTS

Table 3-2. Relationship of Sensor Technology Goals to Thrusts

Subarea / Thrust	Radar Sensor Technology	Electro-Optic Sensor Technology	Acoustics	Multisensor Integration
1. Global Surveillance and Communications	• Allow passive wpn sys engage threat illuminated by remote source. • Active conformal arrays embedded on structures. • High power, narrow beam active apertures. • Demonstrate combined transmit, receive, illuminate, & comm functions. • Improve resistance to countermeasures. • Improve operational performance in severe environments. • Reduce own platform radar cross section. • Deployment of radars on light satellites, RPVs, etc.	• Develop space-qualified 5-year reliable cryo-cooler. • Provide remote, real-time detection of chemical agents. • Demonstrate large-scale multiple color staring FPAs. • Develop miniature low cost, integrated detector/dewar assemblies. • Demonstrate high density uncooled FPA. • Improve survivability of space and airborne platform.	• Evaluate detection limits of very large underwater passive acoustic arrays. • Develop ultra-low frequency underwater acoustic sensors. • Develop network of remote acoustic and seismic sensors. • Evaluate air-propagated acoustic and seismic sensor array networks for low observable detection and tracking.	• Evaluate multispectral electro-optic sensors. • Develop staring thermal imagers for NCTR and ATR. • Integrate multiple color FPA, ladar, and RF sensors. • Develop uncooled thermal imagers supporting NCTR and ATR and combine with radars and passive microwave sensors.
2. Precision Strike	• Allow passive wpn sys engage threat illuminated by remote source. • Active conformal arrays embedded on structures. • High power, narrow beam active apertures. • Light, small, power efficient radar. • Improve resistance to countermeasures. • Continuous theater MTI to track all vehicles. • Reduce own platform radar cross section. • Deployment of radars on light satellites, RPVs, etc.	• Allow passive wpn sys engage threat. • Active conformal arrays embedded on structures. • High power, narrow beam active apertures. • Light, small, power efficient radar for RPVs. • Improve resistance to countermeasures by 100%. • Continuous theater MTI to keep track of all vehicles. • Reduce own platform radar cross section. • Provide capability to detect, track, and engage advanced threats. • Deployment of radars on light satellites, RPVs, etc.		• Integrate IR and RF devices for 100% improvement in target acquisition. • Integrate FLIR and laser rangefinder. • Deploy multispectral electro-optic sensors. • Develop staring thermal imagers supporting NCTR and ATR. • Integrate multiple color FPA, ladar, and RF sensors. • Develop uncooled thermal imagers supporting NCTR and ATR and integrate with radar.

(Continued)

Table 3-2. (Continued)

Thrust \ Subarea	Radar Sensor Technology	Electro-Optic Sensor Technology	Acoustics	Multisensor Integration
3. Air Superiority and Defense	• Counter 1,000-fold reduction in monostatic threat radar cross section. • Active conformal arrays embedded on structures. • Light, small, power efficient radar. • Combine transmit, receive, illuminate, & comm functions. • Provide capability to detect, track, and engage advanced threats including stealthy cruise missiles and aircraft. • Reduce own platform radar cross section. • Target ID.	• Accurate target tracking, identification, and weapon guidance. • Provide capability to detect, track, and engage advanced threats including stealthy cruise missiles and aircraft. • Improve survivability by 100%. • Enhance weapon lethality. • Demonstrate large-scale multiple color staring FPAs. • Develop miniature low cost, integrated detector/dewar assemblies. • Target ID.		• Improve resistance to ECM by 100%. • Improve all weather capability by 1,000%. • Provide combat ID.
4. Sea Control and Undersea Superiority	• Provide capability to detect, track, and engage advanced theater including stealthy cruise missiles. • Radar detection of submarine periscopes and masts.	• Demonstrate aim-point improvement by 100%. • Passive and active IR detection of periscopes and masts. • Active optical (LIDAR) detection of submarines and mines in shallow water.	• Demonstrate multiple line tactical towed arrays. • Demonstrate fiber optic underwater planar array.	• Detect and identify surface target in all weather, day/ night. • Improve submarine detection, classification, and localization by all sensor data fusion at platform, battle group, and theater level.
5. Advanced Land Combat	• Detect and identify camouflaged or foliaged-concealed target. • Rapid minefield mapping.	• Passive imaging for target selection. • Aimpoint selection. • Laser ranging.	• Acoustic detection of low flying heli-copters and aircraft.	• Develop flexible shared aperture, integrated active/ passive sensor suites covering RF, visual, and IR spectral regions. • Combat ID.
7. Technology for Affordability	• Develop low cost producible transmit/ receive arrays for all radar bands and configurations.	• Common sea and land dual color sensor which reduces acquisition cost. • Uncooled FPAs. • Focal plane array producibility.	• Low cost fiber optic sensors and arrays. • Micro-machined acoustic and non-acoustic sensors.	• Shared aperture multimission sensors.

D. SUBAREA ROADMAPS TO REACH TECHNOLOGY GOALS

Table 3-3. Roadmap of Technology Objectives for Radar Sensors

By 1995	By 2000	By 2005
• Adaptive processing sidelobe canceler (30 db) demonstrated. • Wide band active arrays. • Demo 100% increase in SAR resolution (superresolution). • Show 50% improvement in OTH signal-to-noise ratio. • Demo multifunctional radar image while scan and superresolution-critical technology demonstrated. • Special target radar - UHF, low sidelobe, phased array antenna demo. • Detect LO and classify fixed targets and high value stationary targets. • Improved rotodome AEW radar multidomain processing (spatial, temporal, range, and polarization). • SIR-C bistatic SAR imaging demonstrated showing 50% improvement in Radar Survivability. • Demonstrate improved detection of submarine periscopes and masts with reduced false alarm rates.	• Demo space-time adaptive nulling clutter rejection and air target ID capability and survivability features. • High-density wide band phased array. • Demo space-based synthetic aperture interferometer. • Fielded point defense multi-function radar with survivability features and target identification capabilities. • Fielded wideband radar with non-cooperative ID and low RCS. • Conformal phased array antenna AEW radar with adv. ECCM and medium wide bandwidth. • Fielded solid state phase arrays for ballistic missile detection. • Submillimeter wave radar for all weather high resolution space-based detectors. • Space-based MTI radar technologically feasible.	• Demo low probability of intercept for survivability. • Fiber-optic beam steering and phased array control. • Field radar control of high energy weapons. • Low probability of intercept radar with passive RF ranging capability. • Superresolution UWB detection algorithm development (<.01 m²). • Ultra-wide bandwidth SAR foliage penetration and concealed target detection radar. • Very wide bandwidth AEW radar with survivability features and multifunction features (look-out, look-down). • Terahertz radar systems using high speed superconductive electronics. • Demo anti-stealth multistatic radar. • Multimode MTI, SAR, ISAR, and SBR.

Table 3-4. Roadmap of Technology Objectives for Electro-Optic Sensors

By 1995	By 2000	By 2005
• Two-color, stabilized, scanning land/ship IRST integrated with laser range finder. • Shared aperture, IRST, FLIR and television, demonstrated on rooftop. • 100% clutter rejection signal processing demonstrated. • Two-color IRST demonstrated. • Large aperture IRST engineering model. • Hardened dual-band FLIR demonstrated (field). • Targeting laser radar demonstrated. • Large aperture IRST ship imaging demonstrated. • Develop lightweight (<50 lbs), small (<1 ft^3) LADAR.	• Two-color, stabilized, scanning land/ship IRST demonstration model. • Supersonic IR sensor window. • Large optics multiwavelength sensor. • Large aperture two-color IRST. • IR sensor performance prediction models. • FLIR/laser (Flasher) demonstrated. • Large aperture two-color anti-surface capable IRST. • Demonstrate operationally useful LIDAR for environmental sensing. • Field large format FPAs for space-based missile detection and tracking. • Demonstrate high sweep rate LIDAR detection of submerged submarines. • Demonstrate enhanced shallow water mine detection by LIDAR. • Provide coherent LADAR for FLASHER Demo. • Advanced LADARs detection scheme for autodyne tracking and interferometer images.	• Very large aperture multicolor IRST. • Very large aperture multicolor anti-surface capable IRST. • Demo space-based synthetic aperture optical interferometer. • Affordable expendable thermal imager for UAVs. • Multicolor IR/UV/VIS FPAs with large formats. • Multimission large optics IR sensor.

Table 3-5. Roadmap of Technology Objectives for Acoustics

By 1995	By 2000	By 2005
• Processing algorithms for battlefield sensor that increases platform self-noise rejection by 50%. • Demo 25% improvement in detection using very large undersea arrays. • Increase shallow-water mine detection by 100%.	• 100% improvement in battlefield acoustic target classification. • Demo ultra-low frequency (ULF) underwater acoustic sensor showing 30% increased range. • Double detection range of torpedo defense. • Improve power efficiency by 50%.	• Self-noise rejection increase by 100% for Armored System modernization. • Improve smart mine effectiveness 50% using passive EO aim point selection. • 100% improvement in low noise submarine detection.

Table 3-6. Roadmap of Technology Objectives for Multisensor Integration

By 1995	By 2000	By 2005
• Increase target ID by 75% using multicolor IR sensor. • Integrate FLIR and laser range finder. • Demo EO staring imagers for NCTR with radar. • Demo real-time positive hostile ID. • Field demo 2-D imaging radar. • IR, radar integrated sensors.	• Develop network of remote acoustic and seismic sensors. • Auto ISAR capable radar-ship/boat/buoy classifier with scanning capability. • Develop uncooled imagers for low cost NCTR. • Detect and ID camouflaged or foliage-concealed targets using combined EO/RF sensors. • Fielded, integrated EO/radar system for missile track hand-over and fused data imaging. • Field demo integrated IR, radar ESM.	• Field multispectrum IRST with radar ranging. • Multicolor stabilized land/ship IRST scanner integrated with laser rangefinder. • Demo multistatic, anti-stealth radar capable of NCTR. • Real-time fusion of sensor products.

E. R&D IN OTHER ORGANIZATIONS (GOVERNMENT, INDUSTRY, FOREIGN)

1. Government

The DoD R&D efforts in the areas of passive and active sensors have a large range of application to other Government Agencies and Organizations. There has been a substantial increase in the participation from interested Federal agencies in the last 5 years due to expanded activity in environmental sensing and drug detection. Science and Technology activities in Radar, Electro-Optics, Acoustics, and Signal Processing (Non-Cooperative Identification) are coordinated with many government agencies and industry. This technology exchange is aided by numerous civilian associations such as the Aerospace Industries Association, the Electronic Industries Association, and the National Security Industrial Association. The Department of Energy, the National Aeronautics and Space Administration, the National Institute of Standards and Technology (NIST) (Department of Commerce), and the National Science Foundation also provide fora for distribution and coordination with other Agencies and industry.

Passive and Active Radar (including laser radar) technology is being developed by NASA for atmospheric sensing and remote sensing from space, by the Environmental Protection Agency (EPA) and DoE for pollution and effluent monitoring, and by the Federal Aviation Administration (FAA) for windshear detection and velocimetry. NASA is also developing remote sensing techniques derived from DoD S&T developments. In addition, NIST has developed near-field antenna measurement techniques for the characterization of high performance antennas including phased arrays, microstrip elements, and ultra low sidelobe antennas. Measurements are available from 1 to 60 GHz providing gain pattern, polarization, and element excitation for arrays. Wideband pulse techniques are being developed for antenna parameter and scattering measurements for microwave absorbing materials.

There are a small number of research efforts at universities and at the national laboratories on superconducting sensors (both RF and IR) and strained superlattice detectors. A major area in which non-DoD funding is significant in supporting related research is in materials development for superconductors. NASA has astronomy sensor requirements from ultra-violet to LWIR to support planetary and other space exploration projects. NASA efforts in cryogenic cooling for spaceborne sensors are similar to those of DoD. DoE laboratories use fiber optic sensors in many applications. In addition, facilities have been developed at NIST to characterize optical radiation detectors from the near-UV to the near-IR spectral regions. A low background infrared (LBIR) calibration facility has also been developed by NIST to support the DoD calibration effort for infrared focal plane arrays. NSF supports research in the areas of silicon microsensors, biosensors, IR/far-IR detectors, and microelectromechanical devices.

DoD S&T signal processing has significant impact on other Government Agencies. Research into atmospheric and oceanographic processes conducted by DoD is also conducted under sponsorship of National Oceanic Atmospheric Administration (NOAA) of NASA, the Department of Energy, the Environmental Protection Agency, the National Science Foundation (NSF), and the Department of Agriculture (Forest Service). NIST has been responsible for developing environmental prediction, scene models. The model for control architecture has been adopted by NASA, Bureau of Mines, and other governmental agencies including DoD branches. In addition, the NSF supports a number of programs on the remote sensing of atmospheric parameters, focusing on aircraft-based and ground-based measurements. While NSF does not support research in weather prediction per se, support for understanding and measuring mesoscale atmospheric processes, dynamics, and numerical methods can contribute to improved NWP models developed by other agencies such as DoD.

2. Industry

There is significant interaction between DoD and the Industrial Base in the sensor S&T areas. The following highlights current industrial R&D activities in sensor technology.

For active and passive radar R&D within the technology base focuses on development of extremely wideband radar, wideband microwave sources, and antennas including S&T support for active element arrays and conformal arrays. In addition, industry is developing improved techniques for microwave and millimeter wave radiometry using IR&D resources.

In the area of electro-optics, industry R&D is focused on material processing and fabrication of large-scale IR focal plane arrays and fiber optic sensor systems. In addition, Small Business Innovative Research (SBIR) programs are being undertaken to acquire knowledge critical to the achievement of higher yields in the production of HgCdTe infrared focal plane arrays (IRFPAs). These programs will provide insight into the role of precipitates, dislocations, and subgrain structure on the suitability of epitaxial material for

IR detectors and their impact on yield and performance degradation. Studies are being conducted to determine the mechanisms by which defects from the temperature of formation and their behavior during subsequent annealing. Also SBIR work supporting uncooled IR detector technology is directed at improving the temperature coefficient of resistance of bolometric materials. An advance in ferroelectric materials is also being investigated that has application to uncooled detectors.

For signal processing associated with passive and active sensors, industry R&D is primarily related to construction practices and pollution control. It is particularly noteworthy that the ocean and atmospheric technology base in the United States is crucially dependent on federal investment. Available data indicate the IR&D investment in geophysics is less than 5 percent of the Air Force investment; while IR&D investment in electronics is 500 percent of the Air Force's. The limited industrial R&D is a primary reason that environmental R&D is a critical technology for DoD.

3. Foreign

a. Radar Sensors

The U.K., France, and Germany have ongoing efforts in synthetic aperture radar (SAR) and inverse synthetic aperture radar (ISAR) technology. Both the U.K. and Japan are developing active element microwave arrays. France has developed advanced techniques for antenna testing. The United Kingdom's Merlin artillery precision guided munition (PGM) uses an active millimeter wave seeker. The Merlin seeker is used in several internationally developed munitions. The U.K. has a significant effort in laser radar technology; Canada, France, and Germany also have strong ongoing programs.

Every major European country works with laser radars for remote sensing, with Germany and Sweden currently being the most active. France and Germany are investigating laser radars for helicopter detection and recognition. France and Norway are studying the use of radar imaging techniques against naval and lead-based surface targets. Germany, France, and Japan are developing phased array radars for air defense and remote sensing applications.

The CIS has active programs in space-based SAR and laser remote sensing. Their laser radar technology appears advanced, but the relevant technology base is behind current U.S. capabilities.

b. Electro-Optic Sensors

Passive EO Sensors. Many countries are manufacturing passive EO sensors, with primary emphasis in the visible and IR portions:

The U.K. is building a high definition thermal imager with SPRITE detector FLIR technology. The resolution and uniformity of commercial British imaging systems may exceed that of U.S. systems; but the U.S. common module FLIR has higher sensitivity and is better for human viewing applications. The U.K. markets passive night sights with second- and third-generation image intensifiers as well as miniature pocketscopes for night surveillance.

Canada produces a portable FLIR for battlefield and coastal surveillance and air defense target detection and recognition. This FLIR is compatible with low light level TV and LRFs.

France produces thermal imagers for main battle tanks, naval surface-to-air missiles, and fighter aircraft; IR charge-coupled devices (CCDs) for antitank guided missiles, both ground- and helicopter-launched; a passive IRST for naval antiaircraft frigates; and IR linescanners.

Sweden markets a family of high definition, thermographic, real-time imaging and recording systems. These completely portable, rugged systems incorporate SPRITE detectors and can be used for a variety of commercial and military applications, from inspecting electrical lines and testing hybrid circuit boards to imaging military aircraft and vehicles. Sweden also offers an infrared-guided PGM and several "SADARM-type" submunitions, both IR-guided and terminally homing. Germany offers a variety of night vision reconnaissance devices.

Companies in the Netherlands have a long history of manufacturing night vision devices (NVDs). These devices incorporate first- through third-generation image intensifier tubes, IRCCDs, and pyroelectric devices.

Israel produces MCT FLIRs, a Long-Range Reconnaissance and Observation System with a FLIR or TV and laser rangefinder (LRF), laser designators with TV or thermal sights, day/night thermal imagers and CCD cameras, thermal imaging binoculars for RPVs and armored vehicles, a thermal imaging camera with optional data link for real-time fire control, and passive IRST and IR warning systems.

Australia builds an IR intrusion sensor for passive, long-range unattended surveillance such as perimeter defense; and they produce a wide-field-of-view surveillance device incorporating a seven-element MCT SPRITE (signal processing in the element) detector.

Singapore produces a hand-held thermal imaging system for thermal sights, battlefield observation, search and rescue operations, security patrols, and air and maritime navigation.

The Japanese are working on second-generation IR imaging and advanced EO sensors, with the development of a 1000-by-1000 element IRCCD, which is useful for large staring arrays. The Japanese have mastered platinum silicide processing and market 512-by-512 detector arrays commercially. The Japanese are leaders in the area of multiband-capable components using dissimilar compound semiconductor materials. This work emphasizes commercial telecommunications, but the underlying materials and fabrication techniques could contribute to future space and sensor programs.

The CIS produces infrared search and track sets (IRSTs), infrared warning receivers (IRWRs), and LRFs for their fighter aircraft. They manufacture superior thermoelectric detectors and have deployed many EO sensor systems with operational ground and helicopter units. These include first- and second-generation image intensifiers; NVDs for drivers, pilots, commanders, and weapon sights; and television for guiding SAMs.

China is working on night vision technology, including development of low-light CCD (LLCCD) cameras and IRFPAs for both commercial and military applications.

India is developing an indigenous capability to manufacture FLIRs. They have developed and tested passive NVDs for battlefield surveillance and anti-tank missile targeting, armored vehicle driver sights, night vision binoculars, night sights for artillery, and thermal imagers for tanks.

Active EO Sensors. The CIS has active IR equipment including weapon sights, surveillance devices, night driving equipment, laser target designators, laser radar, and infrared spotlights. China has copied CIS designs for active IR equipment.

Greece markets a hand-held artillery laser rangefinder. India has developed LRFs and active sights for tanks and has optimized an IR sniperscope for very low visibility.

South Africa has developed a short-range 120mm laser-homing mortar bomb which is used in conjunction with a laser target designator.

c. Acoustics

Active Acoustics. CIS, U.K., France, and Germany are the primary foreign manufacturers of active acoustics for both mine detection and antisubmarine detection and identification.

Australia is developing a new sonar signal processing system for its proposed surface ship towed array surveillance system.

Passive Acoustics. CIS has employed sound-ranging systems since World War II, and has developed several versions for remote surveillance applications.

Germany, France, U.K., Sweden, and Switzerland offer a variety of artillery weapon systems, munitions, and rockets with acoustic sensors.

Israel and Sweden independently offer acoustic detection systems for helicopters; and India is developing an indigenous capability to manufacture acoustic sensors for perimeter surveillance.

d. Multi-Sensor Integration

Several countries are pursuing the integration of infrared sensors with millimeter wave radar for more reliable and versatile target detection, identification, and tracking. Examples include the French TACED and PGMT missiles and Germany's Smart 155 "SADARM-type" submunition.

Israel's Phalcon airborne early warning (AEW) platform represents an integration of several sensors including radar, IFF, ESM/ELINT, and CSM/COMINT sensors.

The U.K. has developed an unattended, combined seismic/acoustic sensor system for remote surveillance.

Russia has integrated acoustic sensors with EO and/or radar sensors for weapons guidance and has integrated airborne radars with passive sensors for improved air-to-air fire control by employing a "stealthy" operating mode as well as an independent and jam-resistant cueing mechanism.

An important topic in integrating sensors involves the signal and image processing. The U.S. leads in the areas of signal processing and data bases. Related work in Europe and Israel could contribute to the advancement of signal processors and algorithms.

Advanced radar technology and IR sensor programs in Sweden, France, Germany, the U.K., and Japan will require intensive related efforts in signal processing. Ongoing work in the U.K. involves massively parallel signal processors for sonar and radar applications. The Netherlands also has efforts on high-speed data conversion.

Interest in neural networks for signal processing has not been limited to the United States; Japan and European nations conduct neural network research. Japan emphasizes robotic applications. The Netherlands and Germany are exploring neural networks in two- and three-dimensional imaging. Finland and Sweden have research efforts in the use of neurocomputing for pattern recognition.

The CIS is active in neural network technology, but their efforts are in the early stages. In addition, the CIS has developed algorithms for acousto-optical processing of radio signals.

Table 3-7. Summary and Comparison — Sensors

Subarea	NATO Allies	Japan	CIS	Others
1. Radar Sensor Technology	□□□□ O	□□□□ O	□□□□ O	□□ Sweden, Israel
2. Electro-Optic[a] Sensor Technology	□□□ O	□□□ O	□□□ O	□□ [b]
3. Acoustics	□□□ O		□□□□ O	□ India
4. Multisensor[c] Integration	□□□ O[d]	□□□ O[e]	□□	□□ [f] Sweden, Israel
Overall[g]	□□□	□□□	□□□	□□

[a] General category includes FLIRs, IRSTs, NVDs, FOSS, and SQUID sensor systems.

[b] Many countries have or are developing a manufacturing capability for FLIRs, NVDs, and TISs; including Israel, China, India, Greece, Poland, Yugoslavia, Australia, and Sweden. South Africa offers an IR laser-guided mortar bomb. Sweden's IR-guided Stryx PGM is in full production.

[c] Includes both sensor production and associated signal and image processing.

[d] While not predominant in any key aspect of this technology, the United Kingdom and France have specific capabilities of interest.

[e] In comparison to the United States, Japan has limited experience in fielding operational phased-array radars and virtually no experience in developing multiple sensor weapons. Their experience in photonics and high-speed digital processing using parallel processors and neural networks can make a significant contribution to the U.S. development of advanced signal processing.

[f] The sensitive nature of a signal processing technology may limit cooperative opportunities; however, technologies could contribute to critical component developments.

[g] The overall evaluation . subjective assessment of the average standing of the technology in the nation (or nations) considered.

LEGEND:

Position of other countries relative to the United States:

- □□□□ Broad technical achievement; capable of major contributions
- □□□ Moderate technical capability; possible leadership in some technical niches; capable of important contributions
- □□ Generally lagging; may be capable of contributing in selected areas
- □ Lagging in all important aspects; unlikely to contribute prior to 2002

Trend Indicators—where significant or important capabilities exist (i.e., 3 or 4 blocks):

- \+ Foreign capability increasing at a <u>faster</u> rate than the United States
- O Foreign capability increasing at a <u>similar</u> rate to the United States
- — Foreign capability increasing at a <u>slower</u> rate than the United States
- ? Currently <u>unable to assess</u> rate of change in foreign capability vs. the United States

F. FUNDING

Table 3-8. Funding by Subarea
($ in Millions)

Subarea	FY92	FY93	FY94
Monostatic Radar	148	189	203
Multistatic Radar	45	55	48
Passive Electro-Optics	132	138	135
Active Electro-Optics	50	54	44
Active Acoustics	147	149	155
Passive Acoustics	58	80	70
NCTR, Multisensor	35	47	42
TOTAL	615	712	697

Table 3-9. Funding by Program Element
($ in Millions)

PE No.	Title	FY92	FY93	FY94
0601101E	Defense Research Sciences	31.9	34.2	23.6
0601102F	Defense Research Sciences	10.0	10.0	10.0
0602101F	Geophysics	0.0	1.3	1.3
0602102F	Materials	0.0	1.7	1.7
0602111N	Anti-Air Warfare/Anti-Surface Warfare Technology	25.9	27.9	24.4
0602131M	Marine Corps Landing Force Technology	3.0	3.0	3.0
0602203F	Aerospace Propulsion	0.0	3.0	2.0
0602204F	Aerospace Avionics	16.0	16.0	16.0
0602301E	Strategic Technology	17.2	27.7	20.8
0602302F	Rocket Propulsion and Astronautics	0.0	1.7	1.7
0602303A	Missile Technology	2.0	2.0	2.0
0602314N	Undersea Surveillance and Weapons Technology	53.3	61.1	53.2
0602315N	Mine and Special Warfare Technology	10.2	24.1	12.3
0602624A	Weapons and Munitions Technology	0.6	0.9	0.9
0602702E	Tactical Technology	76.5	61.6	67.4
0602702F	Command, Control, and Communications Technology	17.0	16.8	19.3
0602709A	Night Vision Technology	15.0	15.0	13.0
0602782A	Command, Control, and Communications Technology	6.0	6.0	7.0
0603109N	Integrated Aircraft Avionics	2.5	5.1	5.3
0603203F	Advanced Avionics for Aerospace Vehicles	19.0	19.4	19.4
0603214C	Space-Based Interceptors	11.9	17.5	13.0
0603215C	Limited Defense System	30.1	25.8	21.5
0603217N	Air Systems Advanced Technology Development	0.5	0.5	0.5
0603226E	Experimental Evaluation of Major Innovative Tech.	114.4	106.6	127.9
0603250F	Lincoln Laboratory	12.0	12.0	12.0
0603253F	Advanced Avionics Integration	8.0	11.8	15.7
0603270F	EW Technology	16.3	16.4	16.0
0603313A	Missile and Rocket Advanced Technology	3.9	3.8	5.0
0603428F	Space Surveillance Technology	0.0	35.9	41.0
0603569E	Advanced Submarine Technology	21.8	17.4	17.5
0603640M	Marine Corps Advanced Technology	1.0	2.0	2.0
0603707F	Weather System - Advanced Development	0.2	0.4	0.5
0603710A	Night Vision Advanced Technology	22.6	28.4	26.0
0603741D	Air Defense Initiative	0.0	20.0	20.0
0603747N	Advanced Anti-Submarine Warfare Technology	42.0	45.0	46.0
0603772A	Advanced Tactical Computer Science and Technology	5.2	5.2	5.3
0603782N	Shallow Water MCM Demonstration	4.0	8.3	5.0
0603789F	C3 Advanced Development	2.1	2.3	2.2
0603792N	Advanced Technology Transition	13.0	14.0	16.0
	TOTAL	615.1	711.8	697.4

4. COMMUNICATIONS NETWORKING

A. DESCRIPTION OF TECHNOLOGY AREA

1. Scope

Communications Networking uses shared communications media and common hardware and applications software to enable the timely, reliable, and secure production and worldwide dissemination of information from originators to DoD consumers in support of joint-Service mission planning, simulation, rehearsal, execution, and assessment. Communications and decision support subsystems integrate the information needed by decision makers in joint headquarters and in Service headquarters and execution organizations, regardless of its form (voice, data, video, etc.) or where it originated or where it is being used.

2. Communications Networking Technology Subareas

a. Network Management and Capacity Allocation Subsystem

Network management is the collective system intelligence that controls communications. It includes elements that are fluent in communications protocols, thereby allowing the connection of national and international military and commercial circuits in a global network of secure, high capacity links that appears to subscribers as a dedicated, homogeneous system. Capacity allocation entails the monitoring and utilization of available capacity to ensure that service allocations correspond to operational priorities. The dynamism of military command and control imposes a need for frequent adjustments in routing and capacity among competing users to a degree that is foreign to commercial communications systems. The capacity allocation subsystem monitors network service demands and apportions resources according to the priorities of the moment.

The issues in Network Management and Capacity Allocation technology are security and encryption across multiple segments; prioritization, management, and routing of users/applications; affordability of sufficient global capacity; and disciplined allocation and utilization of capacity by operational users in peace as they would use it in war. In specific situations, there could be significant political considerations, as some nations might deny service according to their national policies and allegiances. The possibility of losing communications capacity due to political as well as military action has significant implications for the design of the communications network. The network architecture must be robust enough to absorb the loss of any 3 nodes and still provide essential connectivity to and within any operation or theater.

b. Data Retrieval and Information Production Subsystem

This subsystem enables operational decision makers in headquarters and execution units to plan operations, assess them through simulation, rehearse the selected option, and replan according to unexpected events. Commonality among the Services is the critical subsystem attribute and will be achieved through software modules which are generic in nature, such as inventory control; transportation/route planning; goal programming; and intelligence, maps, weather, and regional demographic and economic data bases. Commonality enables joint operational planning by facilitating coordination of missions in an automated system which links participant organizations and nations. The planning system includes the means to display, manipulate, and consolidate information in image or text formats and to identify data and information inconsistencies that arise due to unequal access to locally generated information, such as tactical reconnaissance products. The focus here is on exploiting the benefits of a distributed architecture and on defining an affordable communications infrastructure to realize a distributed information system.

c. Modular/Programmable Radios

These are radios that can operate in any portion of the spectrum, using any waveform or encryption scheme. Using generic waveform generation circuitry and crypto logic, one basic equipment can be configured to receive and transmit all current and many future signal formats. Development of a standardized design will dramatically improve internal and international interoperability, reduce equipment and software costs through massive economies of scale, facilitate reliability improvements, and generate training and maintenance savings. Embedded Global Positioning System (GPS) capabilities are another significant benefit.

3. Assessment

a. Network Management and Capacity Allocation

Seamless, global communications connectivity that provides any type of information service on user demand is essential to effective command and control. The realization of an affordable and dependable worldwide military communications system depends upon the ability to establish and manage secure multimedia service across a set of heterogeneous communications networks. The acquisition of capacity on existing and imminent commercial networks is an economic consideration rather than a technology problem. The focus of communications networking technology is on automatically establishing and managing high capacity networks, wherever needed, by using a dynamic combination of existing military and commercial communications systems.

Operational commanders have requirements for extensive person-to-person communications as well as access to very large amounts of multi-media data; and, to meet these needs in a timely manner, high capacity communications are needed. Communications capacity is a readily available commercial commodity, but the cost of maintaining a high-capacity military network with global coverage is prohibitive. An alternative architecture which capitalizes on commercial fiber-optic cable and satellite communication (SATCOM) capacity can provide sufficient capacity at an affordable cost. The contribution of the Science and Technology program lies in the integration and extension of military and commercial networks to and within any theater, and in network management, security, and survivability.

The technology required to link military users in a global system of defense communications resources and commercial wideband networks is attainable, and a considerable amount of fundamental work has already been accomplished by the Services in the Multinet Gateway and related programs. This constitutes a useful basis for automated assessment of user demands and priorities, development of protocol, routing, and traffic management algorithms and software and for allocation of network capacity. Virtual gateways and network managers are genuine technology in the sense that they have not been realized in the sophisticated form required in this application, but the critical developmental and acquisition issues related to realization of a global, high-capacity network are more political and economic than technical.

Other issues include controlling the transition from a peacetime, minimum-cost, heterogeneous global communications infrastructure to a responsive, survivable theater system; developing self-learning and self-healing resource control and allocation algorithms; providing continuous service to highly mobile subscribers; attaining the ability to sense internal and external threats and react automatically; and restoring service rapidly.

b. Data Retrieval and Information Production

One of the results of Desert Storm was a realization and acceptance of the need for a joint planning system. The development of a common, modular system is a logical but challenging extension of this trend. Joint-Service operations impose strenuous demands for coordinated mission planning and execution which cannot be realized if each Service maintains independent planning systems and relies upon unique vocabularies and processes. A single, integrated planning system, fabricated from standardized functional modules, could satisfy Service needs while providing the uniformity necessary to efficient joint operations.

As a basis for developing a common mission planning system for use by all Services in all environments, fundamental elements of the planning process—e.g., data and information fusion, transportation, resource allocation, inventory management, route planning, and process optimization—will have to be formulated as routines which fit and function within a standard framework program. Standardization is the enabling feature of the planning system which facilitates joint operations and cross-Service movement of planning, tasking, and inventory information. A minor amount of customization may be needed to tailor the standard functional modules to unique applications, but a goal of 90 percent commonality appears to be attainable.

The principal issues in realizing the mission planning system include developing generic software modules capable of satisfying the needs of each Service and every mission; designing fusion algorithms and applications which consolidate sensor, textual, and reference library information and present it to decision makers in a form that is concise and readily understood; developing efficient algorithms to allow very rapid replanning to accommodate unexpected changes in threat status or in the environment; and developing an efficient, distributed architecture to maximize computing efficiency, enhance reliability and survivability, and minimize network traffic.

c. Modular/Programmable Radios

The proliferation of incompatible radio designs imposes high costs in acquisition inventory levels, maintenance loads, and operational restrictions and burdens. Users must carry several types of radio equipment in order to participate in multiple networks.

Technology exists to provide an alternative in the form of modular designs which can communicate with many types of radios through digital waveform generation and signal processing.

Modular architectures will produce dramatic decreases in life cycle cost and logistics support demands since only a limited number of module designs will be in inventory in contrast to the current practice of introducing a unique equipment for each application. A significant portion of the technology necessary to develop a universal radio has been demonstrated within the Integrated Communications, Navigation, Identification Avionics (ICNIA) program. Using digital storage and waveform synthesizer techniques, a single radio can use a wide variety of signal protocols, modulation techniques, and encryption schemes. The antenna subsystem, which must span many decades of operation frequency, is an area of significant technical risk. Other issues center upon the degree to which the size and weight of a standard radio can be reduced by investment in high density electronic circuitry and how the unit cost of the improved product compares with that of lower performance but less expensive designs.

The critical risk elements are the antenna subsystem which must accommodate a very broad range of frequencies and performance demands; an infosec subsystem capable of containing and protecting the cryptologic necessary for interoperation with a wide variety of radios; the digital subsystem which will generate an inventory of waveforms and network and link protocols; and the transmitter/receiver subsystem which must operate articulately over a very broad range of frequencies.

B. TECHNOLOGY AREA GOALS

Table 4-1. Communications Networking Technology Goals

Subarea	By 1995	By 2000	By 2005
Network Management and Capacity Allocation Subsystem	• Heterogeneous 3-node network.	• Completed set of demonstrations of ability to link individual military network with any available commercial network.	• Ability to integrate, manage, and reconfigure an arbitrary set of media and systems into a robust, militarily adequate network.
Data Retrieval and Information Production Subsystem	• Elementary planning tools, regional data bases.	• Integrated planning system containing advanced tools regional data base, and a menu-driven operator interface.	• Capability to plan, rapidly replan, and oversee execution of any mission from any joint or service HQ.
Modular/ Reprogrammable Radios	• Modular radio architecture 3-frequency bands: HF, VHF, UHF 3-waveforms.	• Miniaturization of the radio architecture development of multiband transmitter/ receiver subsystem, additional waveforms.	• Ability to satisfy any communication need from a standard set of low cost, highly reliable modules.

C. RELATIONSHIP OF TECHNOLOGY GOALS TO THRUSTS

Table 4-2. Relationship of Communications Networking Technology Goals to Thrusts

Thrust \ Subarea	Network Management and Capacity Allocation Subsystem	Data Retrieval and Information Production Subsystem	Modular Reprogrammable Radios
1. Global Surveillance and Communications	• Ability to form and operate worldwide networks as needed.	• HQ level planning for joint theater operations.	• Connectivity from HQ to execution units.
2. Precision Strike	• Connectivity for strike planning and BDA.	• Execution level mission planning.	• Communications connectivity from execution level to higher HQ.
3. Air Superiority and Defense	• Ability to access national sensor products for warning and weapons queuing.	• Ability to assess attacks and assign weapons to targets efficiently.	• Connectivity within and between surface and airborne weapons and sensors.
4. Sea Control and Undersea Superiority	• Battle group communications connectivity.	• Automated mission planning for air, surface and subsurface operations.	• Voice and data communications with air and naval vessels.
5. Advanced Land Combat	• Unit commanders able to access intelligence and sensor products from their vehicles.	• Automated assistance in planning an attack.	• Intra-unit and upper echelon communication.
6. Synthetic Environments	• Enable worldwide access to simulation and training resources.	• Ability to use actual planning systems in training and exercises.	N/A
7. Technology for Affordability	N/A	N/A	N/A

N/A = Not applicable.

D. SUBAREA ROADMAPS TO REACH TECHNOLOGY GOALS

Table 4-3. Roadmap of Technology Objectives for Network Management and Capacity Allocations Subsystems

Technology Set	By 1995	By 2000	By 2005
Network Management and Control	• Intelligent architecture mapping user service to available transmission resources.	• International military internet management information base.	• Autonomous network management, reconfiguration, and reconstitution
Virtual Gateways	• Policy-based gateways between allied networks.	• MLS/policy-based international military internet.	• Space-based global optical virtual network.
Security/Encryption	• Hybrid encryption including distributed keys and public keys.	• Multilevel secure gateway extension to theater.	• Public keying system applicable to high capacity mixed media, military/commercial network.
Multi-media Switching Fabrics	• ATM technology (voice, data, message, video deployable to any) theater.	• Electro-optical integrated military/ commercial switching.	• Multimedia information fully integrated with reference library and instantly available worldwide to any authorized user.
Survivable Signaling and Protocols	• Robust routing algorithms and protocols for theater subnetworks under stress.	• Interoperation between low-throughput military and commercial.	• Global high capacity network connecting theater local area networks.

Table 4-4. Roadmap of Technology Objectives for Data Retrieval and Information Production Subsystems

Technology Set	By 1995	By 2000	By 2005
Planning Tools Modules (ontimization, inventory, transportation)	• Tool box of standardized Operations Research tools within a generic planning system framework.	• Single planning system capable of 2-hour planning cycle.	• Single planning system satisfying joint and service mission planning needs and including expert system techniques, simulation, rehearsal, and rapid replanning.
Reference Library (intelligencel, history, weather, EOB, maps, demography)	• Regional data bases with maps, history and demographics, intelligence, EOB, weather.	• Integrated data base capable of assembling information to respond to menu-driven queries.	• Distributed data base, auto-updated by fusion module capable of responding to natural language queries.
Fusion Module (integration of imagery, IR/EO/RF data, data base update with text)	• Module to combine different sensor products and update textual materal with constrained language.	• Ability to access archived sensor data for BDA. Ability to access reference data (plans and drawings) to aid strike planning and BDA.	• Automated fusion of sensor products and free form text inputs.
Distributed o/s and DBMS	• Three-node classified network demonstrating remote access multi-level security and data quality control.	• Distributed data base including imagery, capable of self-update and auto reconstruction.	• Multilevel secure distributed o/s and DBMS capable of auto reconstruction and repair.

Table 4-5. Roadmap of Technology Objectives for Modular/Reprogrammable Radios

Technology Set	By 1995	By 2000	By 2005
Smart Radio Architecture	• Complete definition of modular radio architecture.	• Demonstrate interoperability of the radio architecture with current freq hop radios and wideband JTIDS, GPS, EPLRS waveforms.	• Miniaturization of 2000 demo including SATCOM capabilities.
INFOSEC	• Definitions of crypto architecture.	• Demonstrate embedded programmable Comsec unit providing multiple functions based on CYPRIS technology.	• Crypto module capable of operation with any operational comsec scheme.
Transmitter/Receiver (XMTR/RCVR) Subsystem	• Concept demonstration using conventional, narrow band XMTR/ RCVR.	• Demonstration of multiband XMTR/RCVR subsystem covering HF, VHF, UHF.	• Miniaturization of multiband XMTR/RCVR subsystem. • Development of SATCOM XMTR/RCVR subsystem.
Digital Subsystem	• Demonstration of protocol and waveform generation using general purpose digital processing.	• Miniature, generic signal processor and waveform generator capable of operating in three bands including wideband waveforms.	• SATCOM processing capabilities added further miniaturization reduced power based on low voltage circuits and on-chip power management.
Antenna Subsystem	• Discrete antennas.	• Multiband antennas covering less than the full bandwidth; multiple antennas required.	• Conformal, SATCOM, and all-band designs.

E. R&D AT OTHER ORGANIZATIONS (GOVERNMENT, INDUSTRY, FOREIGN)

1. Government

Communications networking, in wide and local area nets, is the focus of a great deal of attention on commercial and government agendas. DARPA and SDIO are supporting R&D in this area and these efforts are coordinated with Service programs to avoid duplication and to capitalize on opportunities to utilize technology products as often as possible. Beyond DoD, no government agency invests significantly in the sophisticated technology required to support next-generation military command and control systems. There are a number of efforts that use commercial and military communications technology to solve specific agency problems, such as covert communications and communications with satellites and aircraft, but these are applications of existing technology rather than actual technology development.

2. Industry

The commercial communications field sponsors a great deal of research and development to satisfy the growing demand for individual and organizational voice, data, and video communications. Technology work within the private sector is concentrated on development of improved digital switches and on enhancements to high-bandwidth optical fibers, detectors, and couplers. These products are directly applicable to military communications systems and constitute an important element within DoD's communications networking technology efforts. The success of DoD's Global Surveillance and Communication and Precision Strike Thrust depends directly upon the availability of high-performance commercial fiber optic networks to supplement military communications assets. Other thrusts, such as Computers, Sensors, and Design Automation also rely upon extensive communications capacity to link resources and consumers.

3. Foreign

a. Network Management and Capacity Allocation

Most modern battlefield communications networks have some degree of automated network management. These systems are designed to provide mobile and static subscribers telephone and data communications service similar to a fixed telephone network, but, in a battlefield environment, usually from brigade to co.ps echelons.

The network control centers must perform a wide range of functions in real-time for effective command and control of the network. For example, the latest generation network control system for the RITA system performs the following functions:

- Automated planning and direction of the network.
- Network evolution management.
- Automatic terrain analysis and plotting.
- Automatic frequency management and assignment.
- Communications security management.
- Equipment and personnel management.
- Network status display.
- Switch data base updating.

Many western countries have either developed or purchased integrated-automated area communications systems for their ground forces. The following table outlines the major systems, their developers, and users.

Table 4-6. Integrated Automated Area Communications Systems

System/Equipment	Developer	Users
RITA	Thomson-CSF, France	France, Belgium, U.S.
Ptarmigan	Plessey, U.K.	U.K.
ZODIAC	Hollandse Signaalapparaten, The Netherlands	The Netherlands
SOTRIN	Italtel, Marconni Italiana, and Telettra	Italy
Deltamobile	Ericsson, Norway and Sweden	Norway and 13 export customers
AUTOKO	Siemens and Rhodes & Schwarz, Germany	Germany
DEOS	Marconi Italiana	Denmark
TCCCS		Canada
MRS	Siemens-Plessey, U.K. and Germany	Australia, New Zealand, Oman, Greece, Austria, Switzerland, Malaysia, and several countries in the Middle East
CZMCS	Marconi Italiana	Turkey
RADITE	DIGICOM Consortium, Spain	Spain

Although Russia and other CIS countries product military radio systems capable of digital transmission, most CIS tactical-operational communications systems probably still rely on manual switching and have little, if any, automated network control capability.

b. Data Retrieval and Information Reduction

Automated command and control systems have been used in tactical-operational units since the 1960s. Early systems were designed for specific functions such as artillery fire control or air defense. More recently, the functions of automated troop control systems have expanded to decision making, with the goal of minimizing the time required to collect and analyze situation data, formulate a solution, and prepare and transmit orders to the proper units for execution.

Most NATO member countries have either fielded or plan to field automated command assistance systems. Specific systems are:

- *United Kingdom:* Wavell battlefield C3I, BATES (artillery), Vixen, and ADCIS.
- *Norway:* ODIN-2 automated artillery control system.
- *France:* SIC computerized command system, ATILA (artillery), ADIVA artillery division automation system.
- *Germany:* ABACUS (artillery), ARES (MRLS).
- *Italy:* CATRIN automated C3 system, SEDAB artillery automation system.
- *Norway-Sweden:* AUTHUR artillery radar-C3 system.

The Soviet Union used automated artillery and air defense systems for many years. Many command and control processes in the CIS ground forces are already extensively automated and a general automated C3 system is being developed.

c. Modular/Programmable Radios

Most new generation combat net radios have modular designs and have programmable functions. The use of modular designs allows manufacturers to develop a series of radios with a wide range of variants and diverse capabilities, with a large number of common modules. This simplifies logistics and training, reduces duplication of research and development effort, and improves interoperability. Modular designs also make it easier to upgrade system capabilities by adding or replacing a selected module.

Thomson-CSF, France, is developing the PR4G family of frequency-hopping VHF combat net radios. The PR4G series will consist of airborne, manpack, and vehicular versions which share a large number of modules. The PR4G has an on-the-air frequency reprogramming capability and built-in test equipment.

The CIS has developed the Arbalet (R-163) series of radios including the R-163-2.5, R-163-1K, R-163-1U, R-163-50U, and the R-163-UP. These radios make up an integrated family of HF/VHF combat net radios. At least some of the radios are microprocessor controlled, and have programmable preset frequencies. The radios appear to be modular and probably share components.

Table 4-7. Summary and Comparison — Communications Networking

Subarea	NATO Allies	Japan	CIS	Others
1. Network Management and Capacity Allocation Subsystem	□□□ O	□□□□ O	□□□ O	□□ Includes China, Israel, India, and S. Korea
2. Data Retrieval and Information Production Subsystem	□□	□□□ O[a]	□□□ –	□
3. Modular/Programmable Radios	□□□ O	□	□□□ –	□
Overall[b]	□□□ –	□□□ –	□□□ –	□

[a] France (Thomson-CSF) doing a lot with frequency hopping radios.

[b] The overall evaluation is a subjective assessment of the average standing of the technology in the nation (or nations) considered.

LEGEND:

Position of other countries relative to the United States:

- □□□□ Broad technical achievement; capable of major contributions
- □□□ Moderate technical capability; possible leadership in some technical niches; capable of important contributions
- □□ Generally lagging; may be capable of contributing in selected areas
- □ Lagging in all important aspects; unlikely to contribute prior to 2002

Trend indicators—where significant or important capabilities exist (i.e., 3 or 4 blocks):

- \+ Foreign capability increasing at a <u>faster</u> rate than the United States
- O Foreign capability increasing at a <u>similar</u> rate to the United States
- – Foreign capability increasing at a <u>slower</u> rate than the United States
- ? Currently <u>unable to assess</u> rate of change in foreign capability vs. the United States

F. FUNDING

Table 4-8. Funding by Subarea
($ in Millions)

Subarea	FY92	FY93	FY94
Network Management and Capacity Allocation Subsystem	14	16	19
Data Retrieval and Information Production Subsystem	18	21	28
Modular/Programmable Radios	16	17	12
TOTAL	48	54	59

Table 4-9. Funding by Program Element
($ in Millions)

PE No.	Title	FY92	FY93	FY94
0601102A	Defense Research Sciences	0.5	0.7	0.7
0602204F	Aerospace Avionics	0.4	0.4	0.4
0602232N	Command, Control, and Communications Technology	11.8	13.1	14.8
0602702F	Command, Control, and Communications Technology	3.6	4.2	4.1
0602782A	Command, Control, and Communications Technology	4.1	3.1	4.6
0603006A	Aviation Advanced Technology	1.6	3.9	6.6
0603106F	Logistics Systems Technology	0.8	0.5	0.0
0603215C	Limited Defense System	4.0	4.5	5.5
0603217N	Advanced Aircraft Subsystems	0.3	0.4	0.0
0603218C	Research and Support Activities	1.0	1.0	1.0
0603253F	Advanced Avionics Integration	0.8	0.5	0.0
0603270A	EW Technology	0.6	0.7	0.7
0603728F	Advanced Computer Technology	2.9	2.5	2.0
0603737D	BTI	8.6	7.0	0.0
0603772A	Advanced Tactical Computer Science and Technology	4.2	3.4	5.4
0603789F	C3 Advanced Development	2.6	3.0	5.4
0603792N	Advanced Technology Transition	0.0	5.0	8.0
	TOTAL	47.8	53.9	59.2

5. ELECTRONIC DEVICES

A. DESCRIPTION OF TECHNOLOGY AREA

1. Scope

Electronic device technology includes those components and subelements used to construct electronic systems and subsystems. Three broad classes—or "subareas"—of device technology are involved: microelectronics, RF components, and electro-optical devices. These three subareas provide the essential building blocks—emitters, receptors, processors, etc.—for the "eyes, ears, and brains" of military systems. The functions they provide are common, in whole or in part, to all military systems and applications, including:

- *Radar*—phased arrays, seekers, synthetic aperture, optical, LPI (Low Probability of Intercept).
- *Electronic Warfare*—electronic intelligence, optical and electronic countermeasures, jammers, radar-warning receivers, signal processing.
- *Platform/Weapon Control*—fuzing, missile sensors, missile guidance, actuators and sensing, avionics, ship/satellite navigation.
- *Computation*—analog-to-digital converters, central processing units, memory, man-machine interface, software.
- *Imaging*—staring and scanning focal plane arrays, image processing.
- *Communication*—satellite, tactical, secure, fiber-optic links.

2. Electronic Device Technology Subareas

a. Microelectronics

Silicon-based processors, memories, and other application-specific integrated circuits (ICs) for data/signal processing and control; gallium arsenide (GaAs) digital devices; digital-to-analog and analog-to-digital converters (DACs and ADCs); direct digital synthesizer (DDS) devices; quantum electronic devices; artificial neural networks (ANNs);

high power solid state switc'‹›; adiation-hardened components; micro-electromechanical devices; computer aided de›ign/test techniques; packaging and interconnection technology; and power distribution/energy storage.

b. RF Components

Microwave and millimeter wave monolithic ICs (MMICs/MIMICs), high power and broadband RF vacuum electronic devices, microwave signal conditioning and control components, vacuum microelectronic devices, low noise microwave devices and circuits, Transmit/receive (T/R) modules and subsystems, antennas, analog and mixed-mode CAD systems, packaging and interconnection technology for MMICs, etc.

c. Electro-Optical Devices

Laser materials, lasers, laser diode arrays, infrared sources, optical detectors, IR focal plane arrays (IRFPAs), display and virtual environmental components, photonic/fiber optic devices,opto-electronic integrated circuits (OEICs), optical signal processors, RF/microwave/optical communications, etc.

3. Assessment

a. Microelectronics

Devices, Processes, and Applications. The dramatic growth of microcircuit technology is attributable mainly to advances in silicon (Si) technology and, particularly, to the ability of the semiconductor industry to progressively reduce the size of circuit elements. Motivating effort to achieve smaller feature sizes is the promise of higher functional throughput rates, increased functionality, and lower cost per function—to provide signal processing for automatic target recognition for precision strikes, signal identification, and creation of synthetic environments for training and simulation. Through 1993, the state of the art will be about 0.5 μm and minimum geometries of 0.25 μm will be achievable by 1998 at 3.3 volt operation. The achievement of 0.1 μm feature size will probably be achieved before new device concepts and/or architectures are required.

Driving R&D investment during the 1992-2000 period is the promise of achieving:

- Static RAMS with densities of 64-200 x 10^6 transistors/cm^2.
- Logic devices with device densities of 10-40 x 10^6 transistors/cm^2 (250) nm geometries).
- 16-bit A/D converters at 125 MSPS; 20 bits at 1 MSPS.

- 250-1000 MFLOPS on a chip; > 50 MFLOPS/watt.
- Large chips (> 1-10 cm^2).
- Very high data rates (> 1-40 GHz I/O).
- Multiple technologies on a single substrate, and a system of chips with a device complexity of 10-40 x 10^6 transistors.

Gallium arsenide (GaAs) and other compound semiconductor materials have thus far played a relatively minor role in the digital world. In practically every digital application, silicon continues to dominate, even though GaAs enables faster ICs and better radiation hardness than bulk silicon devices. Still, GaAs and other compound semiconductor materials promise to become increasingly important in the years ahead. Thus, one of the principal aims of DoD is to advance the compound semiconductor tech base to the point where high-performance GaAs and other compound semiconductor devices and circuits will be available to the military on an affordable basis.

Support Infrastructure. Advances in microelectronic circuit performance will require major advances in a broad range of support areas, including: (1) CAD techniques that can provide device-through system-level solutions, (2) nanolithographic technologies encompassing electron-beam, excimer UV, X-ray, and ion beam systems capable of reducing feature sizes within ICs to tens of nanometers, (3) flexible manufacturing methodologies that will permit the rapid and affordable acquisition of advanced integrated circuits for military systems, (4) device-related materials research, (5) packaging and interconnect technology, and (6) on-chip power distribution/energy storage.

Computer-aided design and production activities have become a central pillar of government and industry efforts to shorten development cycles, reduce development and manufacturing cost, and improve product quality. The central concept and benefit of CAD is that the conventional, costly "design-built-test" cycle can be substantially replaced with a design process that is based on accurate computer simulation of performance. Development/production cycles can be shortened and batch manufacturing can be made "flexible" by integrating engineering and manufacturing processes.

The U.S. electronics industry is now well-positioned to make revolutionary advances in the performance, size and weight, and cost reductions of electronic systems through improvement in packaging, interconnect, cooling and maintenance concepts at levels of integration beyond the single chip. In particular, the multichip module (MCM) approach—with and without optical interconnects—offers great promise, and high priority should be assigned to testing standards, procedures, and test strategies. A common system of industrial specifications suitable for commercial and defense applications is needed.

b. RF Components

Solid-State Devices. DoD's flagship effort in this area continues to be the Microwave and Millimeter Wave Monolithic Integrated Circuits program. The objective of MIMIC is to ensure the availability of affordable, reliable, high-performance microwave components in sufficient volume for a wide range of DoD systems, including missiles, radar, electronic warfare (EW), communications, and other smart weapons to achieve air, sea, and land combat superiority and defense. The program has also spawned a broad expansion of device modeling tools, CAD software, and data-supported models relating to microwave/analog devices. A Microwave Hardware Descriptive Language (MHDL), analogous to the VHDL developed during the VHSIC program, is being developed by the three Services and DARPA. They are actively pursuing a software vehicle that will ultimately interface both analog and digital device design with systems design, procurement, and maintenance.

Some associated "non-MIMIC" areas which have shown steady progress are high temperature semiconductors (particularly silicon carbide) and quantum-level devices. In addition, microwave control device technology will continue to be supported by DoD. Included in this category are limiters, filters, miniature circulators, phase-amplitude controllers, and other signal conditioners. As the MIMIC program progresses and module power levels and bandwidths increase and receiver noise figures are reduced, the need for more selective filtering and improved receiver protection increases. Similarly, as solid-state T/R modules are reduced in size and weight and advanced in output power capability to the 10-30 W range, the need for ultrasmall, low-loss, high-isolation circulators grows in importance.

Vacuum Electronics. The alarming erosion of the U.S. technology base in microwave tube technology during the 1980s threatened to impede development of the advanced radar, EW, and communications systems needed by DoD in the next century. In 1990, that trend began to reverse with the advent of increased DoD funding for tube R&D.

Present microwave and millimeter wave power amplifier performance is set by wavelength scaling constraints and various material limitations which conflict with the demands for higher power, higher frequency radar, EW jamming, and high power microwave weapons in smaller package size. The development of power tubes at microwave and millimeter wave frequencies is still largely an art, requiring a wide variety of materials, such as high current density emitters, materials to suppress secondary electron emissions, thermally conductive insulators, and temperature-insensitive magnetic materials. The generation and control of current flow, beam/wave interaction circuits, diagnostic measurement techniques, and vacuum/package technology are other elements complicating the design process. The vacuum electronics community now has available computer design codes which deal with various aspects of the electromagnetic, thermal, and mechanical design of power tubes. When completed, the Microwave and Millimeter Wave Advanced Computer Environment (MMACE) program will provide an integrated solution to the problem of vacuum tube design.

Antenna Technology. DoD investment in generic antenna technology will concentrate on: (1) conformal and multifunctional antennas, and (2) antenna pattern control. In the area of conformal and multifunctional antennas, goals include extra-high frequency/infrared (EHF/IR) integration, EHF monolithic arrays, super-high frequency (SHF) multifunction antennas, array module integration and beamformers, very low sidelobe and adaptive nulling arrays, and printed circuit antenna technology. For antenna pattern control, emphasis will be placed on ferroelectric, phase shifter development, optical control of arrays, analytical/numerical analysis enhancement, and HF antenna development.

Frequency Control and Devices. DoD will support development of ultrastable oscillators and clocks for communications, navigation, surveillance, and target selection systems. Particularly sought will be greater time and frequency accuracy with lower power consumption, ultrahigh stability in small volume and in severe environments, and lower noise close to the carrier, especially in vibrating environments. Applications include satellite, communications, airborne radar, and identification friend or foe (IFF) systems. Payoffs include higher jamming resistance with longer autonomy (radio silence) interval, the ability to detect and classify slow-moving and stealthy targets, and longer battery life and calibration interval for reduced logistics costs.

In addition, DoD will require higher stability, low noise frequency sources from 300 MHz to 20 Ghz. Specifically sought will be two-orders-of-magnitude-improved vibration resistance, oscillator size comparable/integratable with MMIC chips, high efficiency sources, and lower phase noise close to the carrier frequency.

Submillimeter Wave Systems. A capability void exists bounded by conventional RF systems (operating below 100 GHz) on the one hand and optical systems on the other. Filling this void with effective submillimeter wave systems would provide the United States with a major new defense capability. For example, submillimeter wave systems would: (1) overcome the limitations of bandwidth and resolution below 100 GHz, (2) be superior to optical or infrared systems in terms of atmospheric attenuation, and (3) open the door to military applications in which angle-angle imaging of sufficient resolution to extract target features under active engagement environment (that is, dust and smoke) could be implemented by systems of acceptable weight, size, power, and reliability. Recent research in this area has been most promising. For example, laboratory tests of heterostructure field effect transistors (HFETs) with 50-nm gate dimensions have demonstrated the feasibility of receivers operating without cryocooling at frequencies above 300 GHz. Expansion into this untapped region of the frequency spectrum warrants increased DoD investigation.

c. Electro-Optics

Lasers and Laser Materials. DoD investment in this area will be aimed at developing more efficient, reliable, and compact wavelength diverse laser sources for rangefinder/designator, countermeasure, communication, chemical detector, and radar functions. The effective use of lasers on the battlefield has already been established, but more efficient, reliable, and affordable lasers will be needed for all Service applications by the year 2000. Key issues include increasing short pulse efficiency to 15 percent, increasing average power output to 2W per pound for lightweight tactical applications, increasing the available wavelengths of high power laser diodes to about 3.5 μm, and reducing the cost of the diode array that pumps solid-state lasers to less than $1 per peak watt. Another key goal is the development of a producible, high-efficiency, space-qualified, tactical laser. Desired features include wavelength agility, high reliability, light weight, and low cost. These objectives are directly motivated by critical tri-Service needs related to ballistic missile defense, sea/air communications control, enhanced counter-countermeasures and air defense, affordable brilliant weapons, chem/bio/rad force protection, improved manpower efficiency, and improved environment characterization.

Focal Plane Array Technology. Three classes of FPA that satisfy the full range of Service system needs in air, sea, and land combat applications are: (1) high performance scanning arrays, (2) high performance staring arrays, and (3) uncooled staring arrays. The FPA scanning application is suited for shipboard IR search and track (IRST), airborne IRST and FLIR, and navigation applications. Staring arrays satisfy missile seeker, missile warning, and space surveillance applications. The uncooled staring array finds extensive use in weapons' sight, missile seeker, and driver's viewer applications.

Projected system needs over the next 10 years and beyond will require major advances in FPA technology, including: producible FPAs (over 40 percent yield), FPAs with improved uniformity and sensitivity, multispectral FPAs, FPAs 100 times lower in cost, FPAs that operate at higher temperature, smart focal planes, and high-definition television (HDTV) resolution FPAs. These goals map into tri-Service requirements for survivable global surveillance for strategic force projection, worldwide and all-weather force projection, enhanced counter-countermeasures and air defense, affordable brilliant weapons, increased effectiveness of the individual warrior, and improved environment characterization.

Display Components. DoD invests in the display area to provide military systems with new capabilities for high resolution color display technology. Technologies under development include: flat panel displays, light valves, and high performance CRTs and laser systems. Particularly needed are high-information-content displays that range from miniature, helmet-mounted devices, through portable and vehicular systems, and up to large screen displays for command post, shipboard and command centers. Sought are flat panel displays that offer megapixel resolution, consume low power, and provide virtual reality to the "man-in-the-loop." In addition, three-dimensional and stereoscopic displays are needed for robotics applications, while tele-operated systems and situation displays will be developed using laser technology, miniature devices, polarizers, and special optics.

Photonics/Fiber Optics. Photonic materials and devices are being used increasingly in military systems. Examples include the optoelectronic integrated circuit, used in photonic processing, and the opto-microwave integrated circuit, which provides photonic control of microwave phased arrays. Another example is the replacement of the conventional solid-state phased array antenna with a fiber-optic feed system. Fiber-optic technology will also be used to provide sensors for underwater military operations requiring the measurement of magnetic fields, sound waves, and object rotation.

Some of the future goals set for the photonics/fiber-optics area include the development, within the next 10 years, of the following: a local area network (LAN) operating at multigigahertz rates, an OEIC with parallel processing capability to 10 gigaops per second, survivable fiber-optic components, optical interconnects that operate in the multigigabit per second rate, and smart sensing structures. These objectives are driven by tri-Service needs for survivable strategic force projection, worldwide and all-weather force projection, ballistic missile defense on-demand launch and orbit transfer, sea/air communication control, enhanced counter-countermeasures and air defense, affordable brilliant weapons, chemical/biological/radiation force protection, improved manpower efficiency, and improved environment characterization.

B. TECHNOLOGY AREA GOALS

Table 5-1. Electronic Devices Technology Area Goals

Subarea	By 1995	By 2000	By 2005
Microelectronics	• Exploit silicon commercial technology (0.3 to 0.6 μm feature size). • Achievement of a 5 GFLOP digital signal processor via exploitation of new materials, processes, and packaging technology (SiGe, GaAs, SiC, SOI, 2-D multichip modules, etc.) • Digital/analog mixed simulation. • Semi-automatic prototyping.	• Exploit silicon commercial technology (0.2 to 0.4 μm feature size). • Achievement of a 100 GFLOP digital signal processor via introduction of quantum devices, nano-dimensional device structures, multi-component 3-D packaging, area array interconnects. • Concurrent modeling, full simulation, automatic prototyping.	• Exploit silicon commercial technology (0.1 to 0.2 mm feature size). • Achievement of a terra-FLOP digital signal processor via integrated electronic/acoustic/photonic functions, highly miniaturized 3-D multi-layer monolithic assemblies with 90%-by-volume active elements. • Virtual prototyping from battle simulation through concurrent engineering to rapid flexible mfg.
RF Components	• Multifunction, microwave/millimeter wave integrated circuits. • Integrated solid-state/vacuum tube modules for SATCOM. • Affordable active aperture modules for electronically scanned surveillance and targeting radars. • Precise frequency control enabling positive combat identification and anti-jamming communications.	• Photonically driven and/or coupled microwave assemblies, extension to high quality millimeter wave modules. • Combined power from arrays of solid-state devices. • Affordable modules for digital beamforming (send and receive) for intelligent radar and EW systems. • Miniature atomic clocks for multistatic receivers for stealth target detection.	• Integrated microwave, optical, acoustic, digital processing modules for target classification. • Emerging technologies for generating high power microwaves. • Multifunction (radar, EW, comm) integrated array/processors for avionics/vetronics applications. • Monolithically integratable frequency control elements for highly miniaturized systems.
Electro-Optical Devices	• Visible, IR high efficiency laser modules, extended range jammers and designators. • Dual band IRFPAs for missile seekers pixel level image processing. • First generation helmet-mounted high resolution displays, large area projection displays. • 10 Gbit data rate fiber optic interconnects, 4 Gbyte optical disk storage for 10 GHz data processors, integrated optical stress/strain sensors for composite air frames.	• Tunable multifunction laser modules for designation and countermeasures. • Multicolor (UV-IR) staring FPAs for robust seekers and acquisition sights, uncooled arrays for high performance FLIRs. • Megapixel, full color, high resolution smart displays ranging from miniature to wall size for individual and commander situation awareness. • Monolithic optical transceiver chips for interconnections and data bases, 10 gigabyte optical disk storage, 10 Gigabit digital data transfer/channel.	• Integrated multidomain (LADAR, FPA, millimeter wave) smart sensor elements for near 100% target recognition. • 3-D stereoscopic displays for virtual reality (synthetic environment) applications. • Free space layer-to-layer optical interconnects for 3-D integrated monolithic processors, ultrahigh data-rate optical processors for target classification. • Aggregate throughput up to ~10^{12} bits in networks.

C. RELATIONSHIP OF TECHNOLOGY GOALS TO THRUSTS

Table 5-2. Relationship of Electronic Devices Technology Goals to Thrusts

Thrust \ Subarea	Microelectronics	RF Components	Electro-Optics
1. Global Surveillance and Communications	• Develop enabling and leapfrog technology for achieving ultra-high speed (40-60 GHz clock rates. • Low power (0.1μ W/Gate), efficient (>50 Mflops/watt), radiation-hardened ICs. • Silicon devices for reliable and affordable digital and analog VLSI/VHSI signal and data processing. • Low power, single chip, –80 dBc, 1 GHz direct digital synthesizer (DDS) for multimode radio.	• 59-64 GHz TWTs for space communications. • 94 GHz spread spectrum communication system brassboard. • 44 GHz phased array antenna. • Ultra-stable low-noise frequency sources and clocks for global surveillance and communications.	• Space-qualified 1 joule laser. • Photonics/fiber-optics technology for optical communications networks/architectures. • Two-dimensional FPAs of HgCdTe, InSb, extrinsic silicon, photo-emissive and uncooled detectors and associated electronics.
2. Precision Strike	• Microelectronics/Electro-optics/ microwave multifunction integration. • 20-bit, MSPS ADC. • Dense, high-speed packaging.	• Integrate TWT and MIMIC technologies to provide phased array modules both (1xN) and (MxN) arrays for multimode/multifunction radar and EW systems capable of 6-18 GHz bandwidth, 100 W CW or pulsed (high duty) power output and >30% efficiency. • Exploit fast wave/E-beam interactions to develop amplifiers for next-generation EW and radar systems. • 100 W CW, 90-100 GHz TWT.	• High efficiency 1.5-2 μM sources for laser radar and obstacle avoidance. • 200 W CW and 1 joule pulsed high power diode-pumped 2μM laser sources. • Enhanced real-time, multitarget high-data-rate ATR through use of advanced EO and NLO (nonlinear optical) materials (organics, InP, etc.). • Optically controlled OEIC for phase-steerable radars.
3. Air Superiority and Defense	• 20 Gb/s MUX. • Ultrahigh-speed digital signal processor. • Monolithic integration of different devices (HFETs, HBTs, optical detectors, lasers etc.).	• High performance amplifiers operating in diverse frequency bands from 30 to 1000 GHz. • Low-cost, high-duty crossed-field amplifier (CFA) for AN/SPY-1.	• High-power density (1500 W/cm²), low-cost, quasi-CW, laser diode arrays at 807 nm with >40% efficiency for pumping Nd:host solid state lasers (also Thrusts 1, 2, 4, 5).

(Continued)

Table 5-2. (Continued)

Thrust \ Subarea	Microelectronics	RF Components	Electro-Optics
3. Air Superiority and Defense (continued)	• 5-20 GHz digital IC arrays based on GaAs, InP and other III-V semiconductors. • High temperature (350-500°) digital control devices and circuits (SiC, diamond). • 4-bit, 20 GSPS ADC.	• 120 GHz InP HEMT low noise amplifier (LNA) and other low noise, low-power dissipation, high-dynamic range receiver technology for radar, EW, communications and smart weapons applications. • Submillimeter wave receiver gate components of 50 μm gate HFET.	• Monolithic HgCdTe MWIR FPA (1x1 inch). • Multicolor staring FPA (LWIR/MWIR). • Smart FPA with advanced on-chip processing.
4. Sea Control and Undersea Superiority	• Reliable, affordable analog and digital Si CMOS and BiCMOS VLSICs in 30-100 nm thin film Si on sapphire (TFSOS) for teraflops processing (>50 MFLOP/Watt). • Neural computers for ASW detection/ classification. • Producible, reliable Josephson junctions in high temperature superconducting materials. • 20 bit, 1 MSPS ADC.	• Interconnect and packaging technology for MRF, A-X and smart weapons systems. • 2-6 MHz shipboard antenna systems. • Development of high power efficient solid-state sources/amplifiers spanning UHF through millimeter wave frequencies that incorporate linearity and stability supportive of advanced threat missions.	• Compact, moderate power (0.5-10 joules), high efficiency (10%) 1μm laser source for wavelength conversion into visible spectrum for underwater communications, etc. • Fiber-optic interferometric sensor arrays for ASW.
5. Advanced Land Combat	• Enabling and emerging device and processing technologies in the development of high performance integrated electronic, photonic and acoustic microcircuits for sensor, signal and data processing components for Army system modules.	• High performance millimeter wave transmitters for armor/anti-armor radars for fire control at 5 km range. • Higher stability, low noise frequency sources form 300 MHz through 20 GHz.	• High-resolution color displays (color volumetric displays, 43 cm diagonal color panel, miniature flat panel, and patterned polarizer flat panel emissive display) for vehicle and other applications. • Uncooled IRFPA arrays with projected neΔt of 0.03K for rifle sights, surveillance sensors, missile seekers and other Army applications.

(Continued)

Table 5-2. (Concluded)

Thrust \ Subarea	Microelectronics	RF Components	Electro-Optics
6. Synthetic Environments	•Application of VLSI-based simulation techniques and display component technology to training and readiness functions.	•Limited applicability.	•High-resolution color displays for training simulators. •Laser holographic simulators
7. Technology for Affordability	•Develop full spectrum of concurrent engineering tools to rapidly prototype cost-effective systems and improve the affordability and accelerate system insertion of promising new device technologies such as GaAs, InP, or SiGe HBTs and FETs, the resonant tunneling transistor (RTT), SiC and diamond substrates, ANNs, high temperature superconductor (HTS) technology, and ferroelectric structures. •Dense, high speed packaging. •Power distribution down to IC.	•Utilize MMACE to develop high-performance RF sources from UHF to IR responding to tri-service radar, EW and communication needs on a "design for low cost" basis. •Establish balanced tech base for next-generation sources and revitalize industrial capability (design through production). •Evaluate new vacuum tube structures (peniotron, gyro-TWT, gyro-klystron, field-emitter arrays, etc.).	•Development of photonic and fiber optic device technology to enhance signal, data and image processing using stand-alone or hybrid optical/digital approaches. •Exploration of alternative FPA materials/structures (quantum well, superlattice, superconducting. •Compact, moderate power (0.5-10 joules), high efficiency (>10%) 1μM laser source for wavelength conversion into visible spectrum for underwater communications, etc. •Fiber-optic interferometric sensor arrays for ASW.

D. SUBAREA ROADMAPS TO REACH TECHNOLOGY GOALS

Table 5-3. Roadmap of Technology Objectives for Microelectronics

Technology Set	By 1995	By 2000	By 2005
Devices, Processing and Applications	• 0.5 μm silicon ICs in low-volume production. • Process parameters and device models for 250 nm design rules. • C-HFET SRAM with sub-nanosecond access time. • Compressed logic arithmetic function ICs. • Ultra-high-speed digital signal processing. • High temperature SiC control circuits. • 10 bit, 2.5 GSPS ADC. • -80 dBc A/J DDS.	• Microwave/digital integrated circuits. • Demonstration of VLSI implemented in 30 nm TFSOS for TeraFLOPS processing (>50 MFLOPS/watt). • Rad-hard ferroelectric nonvolatile memory. • 14 bit, 1 GSPS ADC. • 256K nonvolatile RAM. • SOI for 200 nm ICs. • SiC device manufacturing.	• Low volume production of 100 nm silicon digital devices. • Microelectronic/electro-optical/microwave multifunction integration. • Production of wafer-scale integration devices. • Widespread system application of high temperature devices (SiC, diamond, etc.). • SOI in < 100 nm ICs.
Support Infrastructure	• Multiple-component VHDL synthesis. • Analog/digital synthesis • VHDL system modeling methodology. • Multichip module (MCM) packaging standards. • Full assessment of QML certification system.	• Advanced package technology transfer. • Widespread adoption of MMST (flexible manufacturing) methods. • Advent of "GHDL," integrating VHDL, MHDL, MMACE, etc.	• Continued development of quantum electronic devices, new semiconductor materials, etc. • First practical nano-electronic devices. • Widespread use of atomic layer epitaxial processes. • Production-line use of X-ray lithography.

Table 5-4. Roadmap of Technology Objectives for RF Components

Technology Set	By 1995	By 2000	By 2005
Vacuum Electronics	• Further development of MMACE tube CAD system. • Demonstration of mm-wave ECM TWT. • Demonstrate high-gain, low noise CFA for radar/missile upgrades and transfer to MANTECH stage. • Demonstrate RF power gain at 10 GHz in vacuum microelectronics devices. • Complete development of a C-band Gyro-TWT.	• Insert MMACE concepts in R&D cycle for advanced microwave tubes. • Apply/exploit high current emitters, diamond deposition for RF windows and circuit isolation, and high-temperature superconducting materials for magnets and e-beam focusing. • Integrated MMACE/MHDL/VHDL CAD system. • 300 GHz compact transmitter for radar and communications.	• UHF to infrared RF sources for 21st century radar, EW, and communications systems. • Complete development of novel slow wave and fast wave tube designs. • Terahertz source development for radar and communications.
Solid State Electronics	• Advances in MMIC technology (amplifiers, oscillators, mixers, etc.) in 1-20 GHz range. • Common module (1xn) array; 6-18 GHz 100 watt MIMIC/TWT module. • Demonstrate space-qualified T/R module and MIMIC QMC transition. • Development of micro-wave SiC power transistor. • Silicon C-band MMIC. • Delivery of InP mm-wave MMIC. • Delivery of 94 GHz ferrite duplexer.	• Production of 5-inch diameter GaAs wafers. • Heterojunction MIMICs. • Multifunction chips available over entire 1-100 GHz range. • Demonstration of module for (nxm) array. • Complete GaAs and InP bulk and epi growth and characterization. • SiC MMICs. • Integrated MMACE/MHDL/VHDL CAD system. • Complete monostatic/multistatic microwave modules. • 50 μm HFET for 300 GHz receivers.	• Production of 6-inch diameter GaAs wafers. • Microwave/digital integrated circuits. • Microwave/optical integrated circuits. • Production of InP MMICs. • Continued development of HEMT/HBT device technology. • Continued development of mm-wave impatt/Gunn devices.
Generic Antennas	• Planar multifunctional antenna. • MMIC SHF multiple beam antenna.	• EHF/IR integration. • High performance conformal arrays.	• Low-loss superconducting antenna feeds. • Antenna/photonics integration.
Frequency Control and Devices	• High-stability oscillators for SINCGARS. • Integrate frequency control functions with MMIC circuitry.	• Miniature atomic frequency standards. • Compensation methods for systematic frequency instabilities.	• Novel, low-noise high-stability frequency sources.

Table 5-5. Roadmap of Technology Objectives for Electro-Optical Devices

Technology Set	By 1995	By 2000	By 2005
Lasers	• Delivery of high power diode-pumped 2 μm laser sources (20 W CW and 1 Joule pulsed). • Complete development of diode-pumped 1 μm laser, 2 μm diode-pumped optical radar, and mode-locked F/O laser.	• Continued exploration of tunable laser materials. • 100 w coherent prototype laser diode array.	• Space-qualified lasers of many types (i.e., blue-green, tunable). • High power (>1KW) diode arrays.
Displays	• Delivery of miniature flat panel and patterned polarizer flat panel emissive display. • Optimize panel structure and fabrication processes for full color flat panel displays and transition to applications. • New miniature helmet-mounted displays.	• 3-D/stereo displays.	• Advanced displays incorporating voice interaction, high density mass data storage, and artificial intelligence technologies.
Photonic/Fiber Optic Devices	• Delivery of 2-D OEIC smart pixel arrays and high-resolution, high-dynamic range SLMs and SLRs. • Continued development of optical memory technology.	• Delivery of a monolithic quantum well detector/MUX. • Optically controlled microwave circuits.	• Application of optical waveguide, optical and microwave components on a single chip.
Focal Plane Arrays	• Demonstrate large-scale MWIR and LWIR detector array producibility. • Demonstrate imaging IR seekrs for multiple missions. • Delivery of monolithic HgCdTe MWIR FPA (1x1 inch).	• Large-scale demonstration of multi-color staring FPAs. • Availability of miniature, low-cost integrated detector/dewar assemblies. • Uncooled thermal imagers. • Delivery of smart FPA with advanced on-chip processing.	• LWIR FPAs using conventional (non-cryogenic) cooling. • Application of alternative detector materials.

E. R&D IN OTHER ORGANIZATIONS (GOVERNMENT, INDUSTRY, FOREIGN)

1. Government

In addition to the well-known tri-Service and DARPA S&T programs in the electronic device area, there is significant R&D being conducted in this area by other government groups. In microelectronics, for example, the Department of Energy (DoE) has a research program in fabricating epitaxial thin films and developing new devices in semiconductor materials. The program encompasses all phases necessary for the realization of new devices, from epitaxial film growth through device design (and fabrication) to testing. Devices under development include ICs and optoelectronic devices. This work includes a strong effort in strained layer materials systems to determine their advantages in modern devices (lasers, transistors, and detectors) as well as research and development of technologies for the radiation hardness of silicon. The materials growth and device R&D program is supported by substantial theoretical work, experimental materials studies including growth and characterization, and development of in-situ diagnostic techniques. DoE programs include improvement in photolithographic sources such as laser-produced x-rays, synchrotron sources, and advanced free electron lasers.

A program at the National Institute of Standards and Technology (NIST) develops measurement tools for use by the electronics industry in the manufacture of semiconductor devices and ICs; provides measurement methods, reference data, standard reference materials, and mathematical models; conducts research in semiconductor materials, manufacturing processes, discrete devices, and ICs; and integrates experimental and theoretical work to provide a solid basis for understanding measurement-related requirements in semiconductor technology. Research activities include basic investigations of the theory and behavior of materials and structures, improvement of measurement methods to characterize materials and devices, metrology, and artifacts for the manufacture of ICs, and the development of special circuits used in characterizing the performance of transistors.

The National Science Foundation (NSF) also conducts semiconductor materials and microelectronic circuit research, and provides strong linkages among universities, industry, and government. The NSF supports investigator-initiated research that advances understanding of semiconductors and semiconductor devices, and that opens new technologies or revolutionizes existing technologies. Research is supported in such areas as compound semiconductor materials synthesis; material and device characterization; lithography (optical/UV, ion/electron beam, x-ray); and VLSI design.

In the microwave area, the flagship efforts in the vacuum electronics and solid-state areas continue to be the DoD/DARPA/tri-Service Vacuum Electronics Program and DARPA's Microwave and Millimeter-Wave Monolithic Integrated Circuits (MIMIC) Program. However, significant RF/microwave effort is being carried on by other government sponsors as well. For example, NIST has developed near-field antenna measurement techniques for the characterization of high performance antennas including phased arrays, microstrip elements, and ultralow-sidelobe antennas. Measurements are available from 1 to 60 GHz providing gain, pattern, polarization, and element excitation for arrays. Wideband pulse techniques are being developed for antenna parameter and scattering measurements for microwave absorbing materials.

DoE has also been active in several areas of photonics/fiber optics and has developed extensive numerical codes that allow predictive modeling on both surface and edge-emitting laser diode arrays. These codes provide a powerful research tool for testing new concepts and designs prior to experimental implementation. DoE's laser program has also focused on issues of heat removal and on providing innovative designs for mounting high power laser devices for optical pumping of solid-state lasers. These designs are targeted toward fusion and isotope separation programs. Visible upconversion lasers suitable for diode pumping with outputs at high frequency have been demonstrated.

Diode array development in the national laboratories is concentrated on the development and qualification of arrays for weapon applications plus fundamental research aimed at understanding the coupling and phasing of the individual diodes in an array. This work has also included the development of edge and surface emitting coherent arrays with advanced features such as on-chip injection locking for control and beam steering. Pioneering work in strained quantum-well lasers offers lower thresholds, greater bandwidth, and a wider choice of lasing wavelengths for excitation of efficient fiber-optic amplifiers.

NASA has R&D programs in optical communications, optoelectronic ICs, optical correlation for automatic object recognition, and solid-state lasers for lidar applications. The research programs in solid-state lasers are conducted at the NASA Langley Research Center and the Goddard Space Flight Center (GSFC). Optoelectronic technology development is done at the Jet Propulsion Laboratory using state-of-the-art facilities in microelectronics fabrication in the Micro Devices Laboratory. Optical communications research is carried out at JPL and GSFC. Advanced research in optical correlation for pattern recognition in almost any orientation is carried out at the Ames Research Center.

NIST has several optoelectronics programs: developing a measurements and standards base to support optical telecommunications, encompassing the characteristics of optical fibers, integrated optical waveguide devices, sources, modulators, and detectors; providing standards and measurement services for radiometry researching optical materials; developing optical sensors; developing ultrastable lasers and their application to spectroscopy; and developing optical frequency standards.

NSF supports research on optical materials; optic and electro-optic devices; and optical systems synthesis. Support is provided through ongoing programs in materials research, physics, computer and information sciences, and engineering. In addition, NSF funds two centers with research related to photonics. The Optoelectronic Computing Systems Center focuses on expansion of the intellectual foundations of optoelectronic systems and devices, and on the discovery and demonstration of new knowledge using proof-of-principle machines. The Center for Telecommunications Research includes a research thrust on fundamentals of lightweight devices.

Calibration facilities have been developed at NIST to characterize optical radiation detectors from the near-UV to the near-IR spectral regions with direct reference to the nation's radiometric scales. A new facility is under development to enable characterization of detectors and provide detector standards in the far-infrared region to approximately 30 micrometers. A low background infrared (LBIR) calibration facility has also been developed to support the DoD calibration effort for infrared focal plane arrays. The capability is being enlarged to provide calibration of new, low background IR detectors being developed for possible employment as sensors.

NSF supports research in the areas of silicon microsensors, biosensors, IR/far-IR detectors, and microelectromechanical devices. Support is provided primarily through ongoing programs in engineering.

Coordination of this broad-based government-supported activity will continue to be carried out by two closely coupled groups.

- JDL/Project Reliance Technology Panel for Electronic Devices (TPED), which was formed to maximize the cooperativeness of the three Services in the development of the technology needed for tomorrow's military systems.
- Advisory Group on Electron Devices (AGED), a panel of industry and government device experts which, for decades, has reviewed and assessed

individual electron device programs in terms of their relevance to current S&T goals, feasibility of selected approach, adequacy of funding and time, and ability to stand up to probable advances in competing technologies. To help OSD develop an overall investment strategy in the electron device area, AGED conducts Special Technology Area Reviews (STARs) to identify/assess new opportunities for R&D. Recent STARs have addressed Analog-to-Digital Converter Technology, Silicon-Based Multimaterial Technology, Electronic Packaging, and Quantum Well Infrared Photodetectors.

2. Industry

Commercial research and development funding is significant in the microelectronics area. The semiconductor device manufacturing industry spends about 15 percent of its gross revenues on R&D. This comprises about 80 percent of the total U.S. expenditure for semiconductor device research, which, for both merchant and captive producers, is estimated to be more than $4 billion annually. However, competitive pressures on this industry segment have forced an increasingly short-term focus onto that investment, with the result that longer-range strategies and research objectives are no longer being adequately addressed. Moreover, the rapid pace of technology development and increasing complexity and sophistication of semiconductors is making it increasingly difficult for a single company to stay competitive. To help maintain a robust U.S. industrial base in this critical technology, industry, government, and academia have established cooperative efforts. The largest and most ambitious of these efforts is the SEMATECH program. SEMATECH was founded in 1988 to address cooperatively the very critical need for upgrading the semiconductor industry's manufacturing capabilities, particularly its fabrication tools. It is a joint technology development effort of the DoD and U.S. semiconductor industry to provide the critical capabilities for manufacturing successive generations of semiconductor products. It conducts a strong in-house development and demonstration activity and works closely with U.S. manufacturers of semiconductor fabrication equipment to provide state-of-the-art tools for semiconductor manufacturers.

Another example of a highly successful cooperative in this area has been the Semiconductor Research Corporation. The SRC was created in 1982 to address long-range generic research and skilled manpower needs cooperatively. It has been funded primarily by the semiconductor industry, but with government participation as well. SRC support of universities has successfully restored and preserved important research activities in universities and has initiated academic study of important semiconductor topics such as packaging, reliability, and manufacturing.

Looking ahead, the commercial sector will continue to develop higher performance, low-cost silicon technologies for microprocessors, DRAMs, SRAMs, ASICs (application specific integrated circuits), and analog circuits for at least the next decade. Gallium arsenide and other compound semiconductor technologies will provide ultrafast circuitry for both analog and digital circuit functions, but only in relatively simple chips and at a significant cost penalty per function compared to silicon.

Within the next decade, silicon integrated circuits will become available with over a billion transistors residing on a chip less than 1 square inch in area and with logic speeds of 500 MHz or higher. These new device structures will require control of deposition and removal of materials in layers down to 10 atoms thick and with laterally defined dimensions as small as 100 nm. To provide that capability, new forms of selective deposition and removal are being vigorously pursued. Technologies include chemical vapor deposition, laser-induced deposition, evaporation, sputtering, ion implantation, plasma and wet etching, and rapid thermal annealing.

The major challenges in wafer processing include: obtaining sufficient understanding of processes so that they can be modeled for optimization and precision control, developing advanced fabrication tools capable of affordably implementing all processes on a high-yield/high-throughput basis in a production environment, and extending the performance of the tools to the deep-submicrometer geometries required in the next decade. New low-temperature process capabilities will have to be established to meet the low thermal budgets required for the fabrication of giga-transistor chips.

The focus of industry-sponsored IC-related materials R&D continues to be the attainment of higher quality and larger silicon wafers, better quality and lower temperature deposited insulators, and improved conductor systems for contacts and interconnections. While that work continues, more exotic material systems are now being considered as well to satisfy the needs of submicrometer-geometry device structures and the desire for additional functionality. Ferroelectric, ferromagnetic, conductor, insulator, and semiconductor material systems are being improved and their applications demonstrated. The heteroepitaxial demonstration of GaAs, Ge_xSi_{1-x} and $Ge_xC_ySi_{1-x-y}$ for IC bandgap engineering, the use of $BaTiO_3$ and $Pb(Zr,Ti)O_3$(PZT) for nonvolatile DRAMs, and the use of copper as a low-cost alternative to the aluminum conductors on ICs are examples.

Turning to the commercial RF/microwave area, GaAs and other III-V semiconductors continue to dominate monolithic microwave integrated circuit (MMIC) technology. However, recent advances in Group IV heterostructure technology, such as the growth of crystalline alloys of silicon and germanium on silicon, suggest that silicon could provide good MMIC performance as well.

The computer industry is reportedly planning use of high speed digital circuits based on SiGe heterostructure bipolar transistors (HBTs). SiGe HBTs, which can also provide 10 to 50 GHZ as analog devices, are particularly attractive since they are largely free of the matching problems experienced by silicon IMPATT diodes in monolithic configurations. Some models even suggest that SiGe HBTs should be capable of a maximum oscillation frequency of 180 GHz (corresponding to a 400 nm emitter finger width). Other recent work suggests that Si/SiGe MODFETs with 500 nm gate lengths should be operable above 10 GHz.

Meanwhile, the MIMIC Program continues to make important progress. Commercial applications looming for MIMIC technology include: Direct Broadcast Satellite Receivers, Collision Avoidance Radars, Intelligent Cruise Control, Intelligent Vehicle Highway System Transceivers, Automatic Toll Collection, Global Positioning Satellite Navigation Aids, and Aircraft Landing Systems.

Insofar as commercial communication satellite applications are concerned, Ku-band and some Ka-band TWTs have joined the growing list of L- and C-band tubes. Furthermore, at L and C bands, solid-state amplifiers have begun to displace TWTs. Currently at C band, solid-state amplifiers have the trade-off edge at power levels on the order of 12 watts or less. But at the 12 to 30 watt level, a fierce competition is in progress with some recent applications going to TWTs (56 to 62 percent efficiencies). Solid-state amplifiers typically have efficiencies of about 33 percent, compared to 50 percent or more for TWTs. On the other hand, solid-state amplifiers have superior linearity, but with linearizers, the amplifier communication characteristics become virtually indistinguishable.

In the EO area, new commercial applications are beginning to be seen, suggesting that this will be a growth industry over the next decade. For example, numerous U.S. companies are using EO technology for such applications as commercial and biomedical measurement instrumentation, optical imagery, and fiber optic systems.

In the field of biomedicine, fiber systems are being used increasingly for diagnostic purposes, and optical medical instrumentation using optical spectroscopy and holographic imaging are being introduced. Commercial test, measurement, and evaluation are making greater use of the spatial light modulator (SLM) for carrying out optical correlation in optical image processing.

In addition, fiber-optic systems have been applied to a wide range of uses, including high-speed data links, desktop and board-level interconnects, telecommunications, and remote sensing.

The key component associated with optical imaging is the focal plane array (FPA). Commercial systems based on the match of the response of the human eye to the characteristics of the silicon FPA are currently available as industrial security cameras, consumer video cameras, electronic still photography equipment, and machine vision.

Industrial process control and energy management are based on the other examples of applications in the SWIR (1 to 3 µm) spectrum. Still other applications have been developed which use commercial platinum silicide (PtSi) FPAs for operation beyond 5 mm. Industrial TV-resolution PtSi cameras have achieved 640 x 480 resolution image quality.

U.S. research in single-mode fiber-optic systems is driven by an ever-increasing demand for bandwidth. For example, in high-definition television, even with data compression, data transfer rates of 135 Mb/sec may be needed. A number of experimental projects are under way to introduce fiber optics to provide commercial information and television service to homes. One of these will provide the initial test of microwave frequency (2 Gb/s) subcarrier multiplexing.

Because of the potential for space-based lasers with these approaches or with the closely related diode-pumped solid-state laser approaches, a number of defense companies are sponsoring R&D projects in diode lasers, which complement the government investments.

3. Foreign

Generally, the U.S. leads all other countries in basic scientific research necessary to develop new component technologies and products. In some areas, however, the Commonwealth of Independent States (CIS) is strong and in some instances rivals the United States. For example, the CIS has developed significant research assets in support of quantum functional electronic devices, III-V materials, nanotechnology, superconductivity, and vacuum electronics. Japan, on the other hand, has traditionally lagged in developing basic scientific knowledge in support of electronic devices. Japan now has several programs dedicated to overcoming these shortcomings. This new Japanese emphasis on basic science represents a significant departure from past practices, and it is not known if these efforts will be successful. In Europe the most important cooperative efforts in advanced electronic devices are occurring in the United Kingdom, Germany, and France under the ESPRIT program. The Netherlands and Italy also have work under way, while the U.K., Italy, Germany, and Switzerland maintain some expertise in high temperature superconductivity. All other countries lag well behind the United States in scientific research related to electronics, although pockets of expertise can be found in East European countries, South Korea, and Taiwan.

In microelectronics, specifically, the United States and Japan share both technological and market predominance in silicon microelectronic devices, but the U.S. is generally ahead in microprocessors and other complex logic devices, while the Japanese lead in memory devices. The European countries in the ESPRIT program have extensive programs in silicon devices, but it is unclear whether these programs will translate into meaningful challenge to U.S. or Japanese technological and market leadership positions. Generally, however, the Europeans lag the U.S. and Japanese, with the lag being somewhat greater for microprocessors than for memory devices. The Commonwealth of Independent States (CIS), which has most of its capability in Russia, generally lags the U.S./Japanese state of the art by 7 to 8 years, with the gap being smaller for memory devices. South Korea excels in the production of dynamic random-access memory (DRAM) devices, and has extensive capability in static random-access memory (SRAM) devices. This capability is based largely on U.S. and Japanese know-how and fabrication equipment.

The United States has lost its once-significant lead in the areas of semiconductor manufacturing equipment and materials technology. Japan now leads the U.S. in semiconductor materials technology, microlithography, test equipment, and other key aspects of IC manufacturing. Several European countries, including the United Kingdom, Germany, and France, have some capabilities in various aspects of production equipment for semiconductor devices. Germany is a world leader in silicon wafers, while Japan leads in both silicon and non-silicon wafers. Russia has never developed the industrial infrastructure necessary for a state-of-the-art equipment and materials industry, but is probably the only country outside of the United States and Japan to make an entire range of semiconductor fabrication equipment.

In the area of RF/microwave components, the United States and Japan share technological and market leadership, while the Europeans lag somewhat behind. Russia has just begun to produce primitive GaAs parts, such as a 300 gate array. Overall, the Japanese are the leader in superconducting low temperature digital Josephson junction devices, although the U.S. still maintains predominance in most other areas of superconductivity.

The CIS is one of the world's largest users and producers of RF tubes, with extensive capabilities in magnetrons, klystrons, backwave wave oscillators, and gyrotrons and produces full lines of TWTs, but these tubes are generally not up to Western standards of power or reliability. The CIS routinely presents its gyrotron work at international conferences and is widely acknowledged as the world leader in high power and high frequency gyrotrons. The CIS applies its gyrotrons to nuclear fusion research and a variety of materials processing and other applications. The U.K. is one of the more advanced tube manufacturing countries. The gyrotron effort in the U.K. is small compared with that of Germany, France, the CIS, or the U.S. The British are doing theoretical work and good experimental work. France's capability in microwave and millimeter-wave tubes is mostly concentrated in the government-owned company Thomson CSF. Thomson is also a pioneer in high frequency backwave wave oscillators (also known as BWOs or milliwatt power levels) and claim capabilities up to 1 THz. France is currently working near or slightly below the state of the art in gyrotron technology. Their gyrotron work appears to be primarily oriented toward nuclear fusion applications.

Germany has an active RF tubes industry; however, it is somewhat limited in its scope. Japan produces a line of TWTs, klystrons, and magnetrons that range in frequency up to 18 GHz. They also have some systems operating in the MMW band; however, these may be powered by solid-state devices. Japan has a gyrotron program and has reported a 500 kW gyrotron with an unknown frequency. The Japanese have also presented gyrotron-related papers at several conferences. Their level of gyrotron technology appears to be quite good but well behind the work done by the Russians, the U.S., France, and perhaps Germany.

The CIS has a well-developed antenna technology, as evidenced by its radar tracking systems. What is not as well known is the CIS' apparent program in developing millimeter-wave antennas of large diameter. They claim to have a 70-meter diameter dish antenna capable of operating at MM-wave frequencies that they use to track objects in space. This could be significant since very good tolerance control is needed over large surfaces to meet this requirement, especially at low millimeter-wave frequencies. Antennas of more moderate size are used on CIS space-tracking ships (SESS), or seen in recent open published articles.

With respect to EO technology, the CIS has the research infrastructure to develop lasers and high density IRFPAs. Many elements are available for military and commercial applications such as thermal imaging systems; IR search, surveillance and track, and guidance systems; and missile seekers. The CIS has produced and fielded first-generation IRFPA systems and has a mature technology in linear InSb focal plane arrays for the 3 to 5 µm wavelength IR band. It is also known to be working on multielement metal-oxide semiconductor InSb linear arrays. In addition, Russia has been working on linear and matrix pyroelectric detector arrays. The linear arrays are made from single crystals of triglycine sulfate, lithium niobate, and barium titanate. The matrix arrays are made from barium titanate. These efforts are applicable for mid- and far-IR wavelength bands. The materials require no cooling and are adequate for those applications where high sensitivity is not required.

There are major R&D efforts within Russia to build second-generation matrix arrays using InSb, HgCdTe, PtSi, and pyroelectric IR detector materials as well as improvements in InSb arrays. Development and limited production of second-generation IRFPA systems are confined, for the most part, to the Western European countries and Japan.

The U.S., the CIS, Japan, and France are conducting research in vacuum microelectronics (VME) display technology and are at the forefront in VME display research and development. France is the world leader and is 2 to 3 years ahead of the U.S., Japan, and the CIS.

Japan and the United States are the world leaders in inorganic electroluminescent (EL) display technology. Japan, Russia, and the U.K. are at the forefront in the R&D of EL displays utilizing organic emitters. Additionally, Finland is actively pursuing research of inorganic phosphor materials and is among the world leaders in this subcategory of EL display technology. The clear leader is Japan, which has been able to achieve enhanced brightness at remarkably low voltages. The U.S. is not currently active in organic EL technology R&D and lags the world leaders by 3 to 5 years.

Countries which are at the forefront of R&D on plasma displays are Japan, the U.S., and France. Available information suggests that all three countries are at the same technological level, each having developed successful prototype, full-color plasma displays.

Liquid crystal display technology may be divided into a number of different technological levels, the most commonly used being the active-matrix LCD (AMLCD).

Japan is currently the world leader in this technology and has an AMLCD manufacturing output exceeding that of any other country. The Japanese currently lead the U.S. in AMLCD technology by 2 to 4 years. Other countries, notably France, the Netherlands, the U.K., and South Korea, are also actively involved in AMLCD R&D. The most advanced type of LCD is the ferroelectric type. Both Japan and the U.K. are at the forefront in ferroelectric LCD technology, though Japan leads the U.K. by about 5 years. The U.S. lag in this advanced area is at least 5 years behind Japan.

With the exception of the CIS, as noted above, the former non-Soviet Warsaw Pact countries and the People's Republic of China are respectively at the most rudimentary levels of research in each of the display technology categories.

Table 5-6. Summary and Comparison — Electronic Devices

Subarea	NATO Allies	Japan	CIS	Others
1. Microelectronics	□□□ –	□□□□ O	□□	
2. RF Components	□□□ O	□□□ O	□□	
3. Electro-Optics	□□□ –	□□□ O	□□	
Overall[a]	□□□ –	□□□ O	□□	

[a] The overall evaluation is a subjective assessment of the average standing of the technology in the nation (or nations) considered.

LEGEND:

Position of other countries relative to the United States:

- □□□□ Broad technical achievement; capable of major contributions
- □□□ Moderate technical capability; possible leadership in some technical niches; capable of important contributions
- □□ Generally lagging; may be capable of contributing in selected areas
- □ Lagging in all important aspects; unlikely to contribute prior to 2002

Trend indicators—where significant or important capabilities exist (i.e., 3 or 4 blocks):

- \+ Foreign capability increasing at a <u>faster</u> rate than the United States
- O Foreign capability increasing at a <u>similar</u> rate to the United States
- – Foreign capability increasing at a <u>slower</u> rate than the United States
- ? Currently <u>unable to assess</u> rate of change in foreign capability vs. the United States

F. FUNDING

Table 5-7. Funding by Subarea
($ in Millions)

Subarea	FY92	FY93	FY94
Microelectronics	312	256	236
RF Components	164	172	174
Electro-Optics	210	211	143
TOTAL	686	639	553

Table 5-8. Electronic Device Funding by Program Element
($ in Millions)

PE No.	Title	FY92	FY93	FY94
0601101E	Defense Research Sciences	27.0	43.0	24.0
0601102A	Defense Research Sciences	24.4	24.2	25.0
0601102F	Defense Research Sciences	17.7	20.4	20.6
0601153N	Defense Research Sciences	24.7	22.9	22.1
0602121N	Surface Ship Technology	0.5	0.5	0.5
0602122N	Aircraft Technology	0.8	0.2	0.2
0602204F	Aerospace Avionics	21.5	21.8	20.6
0602232N	Command, Control, and Communications Technology	0.3	0.3	0.6
0602234N	Systems Support Technology	32.9	39.1	40.9
0602301E	Strategic Technology	40.0	6.0	5.0
0602303A	Missile Technology	0.4	0.6	0.8
0602325A	Chemical Weapons Treaty Monitoring	0.8	2.5	2.8
0602601A	Combat Vehicle and Automotive Technology	0.3	0.3	0.3
0602702F	Command, Control, and Communications Technology	20.5	28.9	29.6
0602705A	Electronics and Electronic Devices	20.0	21.0	21.5
0602708E	Integrated Command and Control Technology	75.0	0.0	0.0
0602709A	Night Vision Technology	4.0	5.0	4.4
0602712E	Materials and Electronics Technology	110.0	54.0	69.0
0602782A	Command, Control, and Communications Technology	0.6	0.4	1.2
0603102A	Materials and Structures Advanced Technology	2.2	4.3	4.5
0603203F	Advanced Avionics for Aerospace Vehicles	6.5	5.9	6.3
0603215C	Limited Defense System	16.7	30.0	8.0
0603217C	IR Focal Plane Arrays	18.0	36.0	8.0
0603217N	Advanced Aircraft Subsystems	1.9	2.1	2.6
0603654N	Joint Service EOF Development	0.2	0.3	0.2
0603737A	Balanced Technology Initiative	5.5	5.7	6.7
0603739E	Semiconductor Manufacturing Technology	208.0	255.0	220.0
0603742A	Advanced Electronic Devices Development	4.0	6.6	7.5
0603792N	Advanced Technology Transition	0.5	0.5	0.3
0603804A	Logistics and Engineer Equipment	1.4	1.3	0.2
	TOTAL	686.3	638.8	553.4

6. ENVIRONMENTAL EFFECTS

A. DESCRIPTION OF TECHNOLOGY

1. Scope

As military technology grows more complex and sophisticated, DoD systems and operations are increasingly influenced by the variability in natural environmental conditions (e.g., weather, seasons, ocean, terrain and/or space), by man-produced phenomena such as acoustic noise from military and commercial ship operations; and by obscurants such as smoke and haze found on the battlefield. The potential leverage of environmental factors must be clearly understood to increase existing system capabilities and performance, take advantage of environmental weaknesses of threat systems, and optimize the design of new systems. Examples of high impact environmental areas include acoustics and oceanography for mine countermeasures and anti-submarine warfare (ASW), terrain surface dynamic effects on maneuver and logistics capabilities, atmospheric and terrain effects on electro-optical and electro-magnetic sensors, ionospheric and space environment impacts on communications and surveillance systems, and environmental realism in synthetic environments. Successful prosecution of this work will provide prototype sensor and sensing technology that improves our capability to quantitatively measure and predict geophysical parameters worldwide; the technology to convert and display raw geophysical data in terms of military significance; and the quantitative understanding to describe, predict and exploit environmental windows of opportunity in the battlespace. Special attention needs to be given to environmental extremes such as arid and cold regions and adverse environments such as shallow coastal waters, where overall performance of systems and activities are typically severely restricted and the cost of design for full performance may be excessive. Greater knowledge and capabilities in these areas can generate large returns on investment.

2. Environmental Effects Technology Subareas

a. Environmental Sensing

This subarea includes sensing strategies and techniques, environmental sensor development, resolution/accuracy/sampling analysis, integrated environmental sensing systems, and in situ and remote sensing algorithm development. The subarea goal is to develop the ability to adequately sample the battle area environment in real time.

b. Environmental Characterization and Prediction

This subarea includes understanding of environmental mechanisms and processes; research for the characterization of the environment; and development of predictive models in the areas of oceanography, acoustics, electro-optics/electro-magnetics, atmospherics, and the space environment. Also included is environmental data basing and retrieval technology, geographic information systems and data fusion algorithms. The subarea goal is an accurate high-resolution representation of the environment in time and space.

c. Scene Generation and Environmental Decision Aids

This subarea includes system/environment performance simulations, environmentally realistic battle scene generation, and environmental decision aids. The subarea goal is to exploit environmental windows of opportunity and avoid environmental surprise.

3. Assessment

The environmental effects technology relates to virtually all aspects of DoD operations in that all weapon systems and military operations are affected by the environment in which they operate. Specific examples follow:

- Using knowledge of environmental effects, researchers have, through selective filtering, optimized the performance of infrared (IR) sensors to provide an order of magnitude increase in the signal-to-noise ratio of currently fielded IR systems. In addition, understanding the effects of atmospheric conditions on terrain propagation of seismo-acoustic signals will enhance the performance of ground-based seismo-acoustic sensors for weapons targeting and passive battlefield surveillance.
- The Array Heading Rose noise minimization technique for acoustic towed arrays, recently transitioned from the tech base to fleet use on SURTASS, has shown signal-to-noise improvements of up to 6 dB, depending on the

horizontal directionality of the ambient noise. This has resulted in significantly increased detection performance, at greater ranges and with longer holding times.

- Current smart weapons and automatic target recognition systems have high false alarm rates when tested in a variety of environmental conditions. Integration of comprehensive environmental knowledge into the logic modules, design, and testing and evaluation of these systems will dramatically reduce false alarms and increase their effectiveness.
- Electro-magnetic fluctuations in the ionosphere degrade communications and radar range and azimuth performance, and can especially degrade the capability to detect low-observable targets at night. Creation of regions of artificially enhanced ionospheric ionization may enhance overall radar performance, day and night; permit surveillance and target acquisition at closer, possibly tactical, ranges; enable high-resolution detection and tracking of very small radar cross-section targets; and improve communications. Magnetic ASW and minehunting sensors, spaceborne systems, and communications performance are also adversely affected by ionospheric disturbances. The development of predictive ionospheric models will enhance frequency management for maximum effectiveness, help protect spaceborne systems, and enhance effectiveness of magnetic sensor systems.

a. Environmental Sensing

Improved techniques and instrumentation for environmental sensing are essential to enhance an extremely sparse data set. In general, data are not adequate to sufficiently characterize the global, battlefield, or target environments. Efforts will focus on developing in-situ and remote sensing capabilities with a goal of developing integrated synergistic systems for environmental measurements with global coverage from space, air, surface, and underwater.

Particular emphasis will be given to techniques and instrumentation which will acquire data in battle-denied areas. Other areas of importance include typically remote and data sparse regions such as the cold regions of the earth, high atmosphere, and near-earth space environment. Special effort will be focused on the coastal zone, a high potential conflict area which is environmentally challenging in that ocean, atmosphere, subsurface, and near-shore conditions are highly coupled and rapidly changing in time and space.

b. Environmental Characterization and Prediction

Ocean circulation and structure models are progressing rapidly but are heavily dependent on sparse surface and undersea data sources. High horizontal resolution, eddy-resolving ocean circulation models are being coupled to ocean basin and high-resolution, mixed-layer models to resolve the ocean with sufficient detail for improved performance prediction of acoustic ASW systems. Future improvements include the coupling of the atmosphere with the ocean mixed layer through the addition of a marine boundary layer model, which will include two-way interaction between the ocean and the atmosphere. Advanced in situ oceanographic measurements such as acoustic tomography will help provide real-time input for the predictive models and for developing a tactical oceanographic data base. New techniques in data acquisition from various sources and for data assimilation into numerical models are required if the predictive systems are to perform acceptably.

Underwater acoustics drives much of the ocean modeling effort with the objective of supporting the successful development and use of ASW surveillance systems, ASW weapons systems, and ASW countermeasures. Acoustic propagation and reverberation models are the primary environmental elements of active sonar models, supporting both the battle group multistatic sonar system and the low-frequency active acoustic system. Determination of high-resolution directional ocean noise properties is essential to the performance of deployable active and passive sonar systems. New spatial and temporal statistical measures support acoustic system development efforts as well as operations strategy. High frequency acoustic models, ocean modeling, optics, and EM models support new efforts in the important area of underwater mine detection.

The physical processes governing mesoscale atmospheric (500 to 800 km) dynamics are, in general, known well enough for the serious pursuit of predictive systems to support tactical decisions regarding weapon systems employment, but the effects of these dynamics on scene clutter for strategic sensors are poorly understood and additional measurements are required. Recent modeling of atmospheric processes at battlefield scales is demonstrating that the computational power is nearly available, that numerical techniques are improving rapidly, and that the data requirements for the predictive models may be achievable. High-resolution tactical atmospheric models will be developed to integrate locally acquired battlefield data with regional or global data to support the tactical commander with definitive 3- to 48-hour forecasts for weather conditions in the tactical area of interest. High-resolution predictions for rainfall and electro-optical/infrared (EO/IR) propagation, for instance, will be coupled directly with terrain models to generate mobility predictions for tactical planning and EO/IR target signature and background predictions for weapons selection.

Surface terrain variability and dynamics as driven by weather events has profound effects on surface activities such as maneuver and logistics as well as system performance. The ability to characterize these conditions in terms relevant to system performance is critical to the ability to predict and simulate environmental conditions and effects.

The primary focus for strategic defense is on the effects of the natural environment on surveillance sensors and kinetic kill vehicle seekers. Earth, earth limb, and celestial backgrounds add radiance and clutter to the scene that decreases the effective signal-to-noise ratio. A combination of phenomenology models and field measurements provide the basis for the Strategic Scene Generation Model (SSGM), which will provide realistic background scenes and target signatures. The primary models are the Strategic High Altitude Reliance Code (SHARC) for the earth limb and the Celestial Background Scene Descriptor (CBSD) for celestial background. Existing earth background codes, such as GENISIS, are being updated for strategic use. Recent and planned field measurements include the Infrared Background Signature Survey (IBSS) and the Cryogenic Infrared Radiometer and Interferometer for Shuttle (CIRRIS IA) flown on STS-39, and the two-year Midcourse Space Experiment (MSX) to be launched in late 1993.

c. Scene Generation and Environmental Decision Aids

Measurement and modeling of the dynamic electro-magnetic and seismic/ acoustic character of terrain and the atmospheric boundary layer are leading to the realistic simulation of scenes for evaluation of conceptual and prototype smart weapon/automatic target recognition (SW/ATR) systems. Simulation allows early consideration of a variety of operational conditions in weapon design as well as optimization of test and evaluation efforts and the translation of sparse test data to a variety of other conditions and scenarios. The Smart Weapons Operability Enhancement program is the integrating force for DoD technology base efforts to consider systematic incorporation of the environment into the research, development, test, and evaluation process for SW/ATR devices.

Targeting and mission planning, including the choice of weapons and tactics, depend largely on the environment in which they will be used. High-resolution weather prediction techniques and algorithms known as electro-optical tactical decision aids (EOTDAs) are being developed to assess probable target signatures, background signatures, and atmospheric effects. The products available to the tactical commander will permit proper selection of weapons and tactics for the given target and the expected environmental conditions. Special emphasis is given to the ability to model and simulate those conditions that are most dynamic or restrictive to system or activity performance such as cold regions, shallow water, and the desert. Tactical oceanography provides the fusion of environmental data and computer-based predictions and simulations for combat advantage. This information management technology has the potential to improve our operational use of available sensor and weapon systems in the field. It will draw heavily on simulation techniques to develop environmental decision aids for multi-mission applications.

For strategic defense the Strategic Scene Generation Model is in its third version and is being successfully employed in sensor design work and architecture trade studies. The SSGM technology is also being utilized on tactical problems.

B. TECHNOLOGY AREA GOALS

Table 6-1. Environmental Effects Technology Goals

Subarea	By 1995	By 2000	By 2005
Environmental Sensing	• Complete design for regional ocean observing system. • Technology for remote atmospheric profiling.	• Global environment observing system. • New family of affordable environmental sensors.	• Adaptive multispectral remote sensing. • Accelerate insertion of new space environment monitoring technologies fivefold. • Coupled ground/ space-based environment profiling.
Environmental Characterization and Prediction	• Global predictions of ocean circulation. • Range dependent 3-D acoustic models. • Shallow water acoustic model. • Dynamic radiation models. • Ionospheric/magnetospheric specification/forecast models.	• 24 hour high-resolution battlefield forecast capability. • Basin-scale eddy-resolving ocean models. • Range-dependent EM/EO models. • Global updatable GIS. • Sensor-driven ocean/ acoustic models. • Real-time obscurant characterization. • Integrated space environment model. • Semi-automatic specification and forecasting with integrated space environment model.	• Global description/ prediction at tactical scales. • Model-generated environment for performance prediction. • 48- to 72-hour battle-scale environment prediction. • 50-fold improvement in space environment hazards prediction.
Scene Generation and Environmental Decision Aids	• Integrated weather effects decision aids. • ATR scene metrics specification. • Strategic scene generator w/background clutter. • Shallow water system/environment simulations.	• Strategic systems applications package. • ATR DT&E mission planning via environmentally driven synthetic scene generator. • Air refueling tactical decision aid. • Ocean information network.	• Automated IR/MMW scene clutter generator. • Environmental virtual reality mission rehearsal capability. • Real-time weather models for simulators.

C. RELATIONSHIP OF TECHNOLOGY GOALS TO THRUSTS

Table 6-2. Relationship of Environmental Effects Technology Goals to Thrusts

Subarea / Thrust	Environmental Sensing	Environmental Characteristics/ Predictions	Scene Generation and EDAs
Global Surveillance and Communications	• Complete design for regional ocean observing system. • Adaptive multispectral remote sensing. • Coupled ground/space-based environment profiling.	• Global updatable GIS • 48- to 72-hour battle-scale environmental prediction. • Real-time obscurant characterization. • Dynamic radiation models. • Integrated space environment model.	• Strategic scene generator w/background clutter. • Strategic systems applications package. • Environmental virtual reality mission rehearsal capability.
Precision Strike	• Adaptive multispectral remote sensing. • New family of affordable environmental sensors. • Coupled gound/space-based environment profiling.	• Global description/ prediction at tactical scales. • Model-generated environment for performance prediction. • 48- to 72-hour battle-scale environmental prediction. • Real-time obscurant characterization.	• Integrated weather effects decision aids. • Automated IR/MMW scene clutter generator. • ATR scene metrics specification. • ATR DT&E mission planning via environmentally driven synthetic scene generator. • Environmental virtual reality mission rehearsal capability. • Real-time weather models for simulators.
Air Superiority and Defense	• Adaptive multispectral remote sensing. • Technology for remote atmospheric profiling. • Coupled gound/space-based environment profiling.	• Global description/ prediction at tactical scales. • Range-dependent EM/EO models. • Model-generated environment for performance prediction. • 48- to 72-hour battle-scale environmental prediction.	• Integrated weather effects decision aids. • Automated IR/MMW scene clutter generator. • ATR scene metrics specification. • Air refueling tactical decision aid. • Environmental virtual reality mission rehearsal capability. • Real-time weather models for simulators.

(Continued)

Table 6-2. (Continued)

Subarea / Thrust	Environmental Sensing	Environmental Characteristics/ Predictions	Scene Generation and EDAs
Sea Control and Undersea Superiority	• Complete design for regional ocean observing system. • Global environment observing system. • Coupled gound/space-based environment profiling.	• Global predictions of ocean circulation. • Basin-scale eddy resolving ocean models. • Range-dependent 3D acoustic models. • Range-dependent EM/EO models. • 48- to 72-hour battle-scale environmental prediction. • Sensor-driven ocean/acoustic models. • Real-time obscurant characterization.	• Shallow water system/environment simulations. • Ocean information network. • Environmental virtual reality mission rehearsal capability.
Advanced Land Combat	• Technology for remote atmospheric profiling. • New family of affordable environmental sensors. • Adaptive multispectral remote sensing. • Coupled gound/space-based environment profiling.	• Range-dependent EM/EO models. • Real-time obscurant characterization. • Global description/prediction at tactical scales. • 48- to 72-hour battle-scale environmental prediction.	• Integrated weather effects decision aids. • ATR scene metrics specification. • ATR DT&E mission planning via environmentally driven synthetic scene generator. • Automated IR/MMW scene clutter generator. • Environmental virtual reality mission rehearsal capability. • Real-time weather models for simulators.
Synthetic Environments	• Technology for remote atmospheric profiling. • Coupled gound/space-based environment profiling.	• Range-dependent 3D acoustic models. • Range-dependent EM/EO models. • Global updatable GIS. • Real-time obscurant characterization. • Global description/prediction at tactical scales. • Model-generated environment for performance prediction. • 48- to 72-hour battle-scale environmental prediction.	• ATR scene metrics specification. • Strategic scene generator w/background clutter. • Shallow water system/environment simulations. • ATR DT&E mission planning via environmentally driven synthetic scene generator. • Automated IR/MMW scene clutter generator. • Environmental virtual reality mission rehearsal capability. • Real-time weather models for simulators.

D. SUBAREA ROADMAPS TO REACH TECHNOLOGY GOALS

Table 6-3. Roadmap of Technology Objectives for Environmental Sensing

Technology Set	By 1995	By 2000	By 2005
Ocean Sensing Capabilities	• Millimeter wave humidity sounder. • Microwave wind stress algorithms. • Millimeter wave imager/sounder. • Air dropped or unmanned air vehicle deployed temperature, salinity and current sensors.	• Multibeam altimeter measurements of ocean surface slope vector. • Moored, drifting, and unmanned undersea vehicle deployed environmental sensors. • Multisensor data fusion.	• Integrated ocean observation system. • Acoustic tomography system.
Sensing Technology for Atmospheric and Terrain Specification	• Real-time data retrieval. • Multispectral temperature retrievals. • Multispectral cloud specification. • Passive/covert wind sensor. • Mobile vertical environmental profiler. • Fluorescent target detection. • Sensor technology for atmospheric refractivity in coastal zones.	• Multispectral humidity sounder. • Space lidar experiment. • Automated atmospheric profiler for Artillery Met. • Standoff fluorescent lidar remote detection. • Mobile Metsat CAL/VAL capability. • Eye-safe, solid-state lidar demonstration for global wind profiles. • Automated hyper-spectral data exploitation system. • Super conducting gravity sensors. • Coastal zone aerosol distribution sensing technology.	• Space-based doppler lidar. • Coupled ground/space-based covert wind profiler. • Moving ground vehicle metsat receiver. • Environmentally adaptive sensing for target features identification. • High resolution, high density temperature, humidity profiler.
Space Environment Sensing Technology	• Space debris detector prototype. • Spacecraft charge control system prototype. • Photovoltaic array space power plus diagnostics experiment. • Low earth orbit plasma experiment. • High resolution spectroscopy of celestial sources.	• Compact space environment anomaly monitoring technology. • Solar mass ejection imager prototype.	• Space environment anomaly prototype. • Accelerate insertion of new space environment monitoring technologies fielded. • Space-based solar electro-optical sensing technology.

Table 6-4. Roadmap of Technology Objectives for Environmental Characterization and Prediction

Technology Set	By 1995	By 2000	By 2005
Battlefield Scale Environmental Prediction Capability	• Atmospheric effects simulator. • Multisensor data fusion. • Real-time cloud forecasting. • Automated 6-hour tactical forecasting capability.	• Tactical forecasting system. • 24-hour high-resolution battlefield forecast capability.	• Enhanced low observable detection. • 48- to 72-hour battlefield environment prediction.
Ionospheric Specification for Enhanced Surveillance	• Semi-empirical specification model. • Ionospheric heater initial operations. • Ionospheric storm specification capability. • Demonstrate UV ionospheric mapper.	• Ionospheric-neutral coupling model. • Chemical plasma control techniques for hypervelocity vehicles. • Globally coupled space environment models.	• Reduce outages 20% for disturbance free communications. • First principle model driven by real-time data fivefold reduction on space track losses due to enhanced neutral density specs.
Real time Environmental Chacterization	• Rapid archived environmental data retrieval. • Implement updatable GIS. • MMW scattering dynamics of frozen surfaces.	• High speed asynoptic data assimilation and fusion. • Automated environmental feature extraction. • Seismic/acoustic response inversion for snow/soil character.	• Algorithms for real-time environmental data characterization. • Real-time dynamics of frozen surface physical/EM properties.
Tactical Ocean Area Undersea Warfare Models	• Shallow water propagation, noise and reverberation. • Shipboard predictive capability.	• Shallow water non-acoustic models (magnetics, periscope detection). • Environmentally adaptive acoustic processing.	• Integrated under/above sea ASW models. • Sensor-driven acoustics models.
Large-Scale and Shipboard/Tactical Ocean Models	• North Atlantic Basin model. • Western Mediterranean model. • Air-ice coupled model. • Parallel processing for ocean models.	• Global ocean prediction--data-driven models. • Marine boundary layer coupling. • Coastal ocean forecast. • Semi-enclosed seas model. • Global ocean parallel processing.	• Coupled ocean/atmospheric forecast system. • Asynoptic real-time data assimilation. • Shipboard ocean model parallel processing.
Space Environment Characterization/Prediction	• Magnetosphere specification/forecast model. • Integrated space environment model.	• Charging verification prediction capability. • Space debris image processing mode.	• 50-fold improvement in space hazards prediction.

Table 6-5. Roadmap of Technology Objectives for Scene Generation and Environmental Decision Aids

Technology Set	By 1995	By 2000	By 2005
Strategic Scene Generation Technology	• Target and background measurements. • Strategic scene generator. • Midcourse background specification.	• Celestial IR back-grounds. • Background clutter scene generator.	• Multiple source global scene generation.
Tactical Scene Generation Technology	• Environmental sys-tems performance interactions. • IR scene codes. • Millimeter wave scene codes. • Interactive scene visualization models of battlefield atmos-pheres.	• ATR scene metrics specification. • Multisensor scene generation. • Shallow water acoustic field visualization.	• Integrated MMW scene generation. • Autonomous sys-tems design criteria.
Electro-Optical/IR/ Millimeter Wave Propagation Codes	• MODTRAN code. • Optical turbulence compensation. • LOWTRAN maritime aerosol model. • SHARC code. • CBSD code.	• Forecasting capability-atmospheric structure effects.	• Improved EO codes in high variability regions.
Environmental Simulations and Decision Aids	• Acoustic decision aids for benign terrain. • Integrated weather effects decision aids for heavy forces.	• Shallow water ASW and mine countermeasures simulations. • Coastal region EM/EO variability simulation. • 3D two-way atmospheric acoustic simulation. • Integrated decision aids for light units. • Medium resolution terrain simulation.	• Shallow water decision aids. • Environmental models for virtual reality. • Automated decision aids for battlefield applications. • Improved resolution terrain simulation.

E. R&D IN OTHER ORGANIZATIONS (GOVERNMENT, INDUSTRY, FOREIGN)

1. Government

Research into atmospheric and oceanographic processes is conducted under sponsorship of the National Oceanic and Atmospheric Administration (NOAA), NASA, the Department of Energy, the Environmental Protection Agency, the National Science Foundation (NSF), and the Department of Agriculture (Forest Service).

For example, the NSF supports a number of programs on the remote sensing of atmospheric parameters including lidar and a variety of cloud micro-physical measurement systems. NSF's program in mesoscale meteorology is focused on the improvement of theoretical and numerical (descriptive) models of mesoscale phenomena, the development of new instrumentation, supporting field experiments to gather special research data sets, and the use of the data in diagnostic studies of mesoscale phenomena. While NSF does not support research in weather prediction per se, support for understanding and the parameterization of mesoscale atmospheric processes, dynamics, and numerical methods can contribute to improved numerical weather prediction models developed by other agencies such as the DoD.

2. Industry

Industry R&D is very limited and is primarily related to environmental protection issues, such as construction practices and pollution control. rather than to environmental sciences. It is particularly noteworthy that the ocean and atmospheric technology base in the United States is crucially dependent on federal investment; for example, available data indicate that the IR&D investment in geophysics is less than 5 percent of the Air Force investment, while the IR&D investment in electronics is 500 percent of the Air Force's. The limited industrial R&D is a key reason that environmental R&D is a key technology for the DoD.

The industrial and manufacturing base for weapon system environments is made up of subsidiaries and small divisions of larger diversified corporations, small companies, partnerships, and individual consultants. Estimates place this total industry at about 1,000 small groups (excluding universities) of scientists and technologists working on today's defense and commercial environmental problems. The supporting industrial and manufacturing base includes the operational environmental forecasting industry, instrument design manufacturers, and specialized testing and fabrication facilities. Operational forecasting members are typically ocean transportation companies interested in optimum track ship routing; airlines interested in optimum path aircraft routing; off-shore oil platform operations; and local area or city forecasting firms which provide city managers with predictions of local weather patterns. The field of instrument design manufacturing includes commercial enterprises which provide equipment for data telemetry, storage, and processing; electronic profilers and vertical atmospheric sampling equipment; and instrumentation to measure ocean temperature, color, acoustics, tidal waves, and depth. Specialized testing or fabrication facilities are provided by a small group of firms which manufacture controlled pressure test vehicles, altitude simulation test chambers, and in-tank sea ice dynamics testing facilities.

Weapon system environment technology relies on the hardware and software manufacturing segments that address computationally complex problems. The continued health of the U.S. computer industry will be of particular importance. Future military capabilities based on this technology are expected to require a significant number of advanced, high capability computing systems, many of which will be hardened to withstand operational conditions.

Universities also contribute to this technology area through efforts in studying weather forecasting, climatology, ionospheric physics, meteorology, and other atmospheric, oceanographic, space, and geological research.

3. Foreign

Because of international cooperation (government and academic) in oceanography and meteorology, there is a high level of international activity and capability directly relating to important military applications. These efforts all contribute to our understanding of and ability to model complex tactical conditions and scene dynamics.

Ongoing research and development related to the Environmental Effects indicates a potential capability to contribute to meeting the challenges and goals identified:

- Undersea acoustic research, especially that correlated with bathymetry data
- Accurate predictions of localized weather conditions
- Effective integration of remote sensing data
- Improved modeling and simulation of scene dynamics.

Agreements with Western nations are common in environmental research. The global nature of the atmosphere and the oceans makes such cooperation comfortable and obvious. An example of an existing agreement involves work with the Germans on the interpretation of synthetic aperture radar signals from the sea surface. NATO supports a major ASW research laboratory at LaSpezia, Italy. According to recent studies, shallow water ASW is a high priority for our NATO allies and is now emerging as a prime concern for the United States as well. The Army has a data exchange agreement with Canada on atmospheric effects and is participating with other NATO countries in a major field evaluation of EO/IR sensors under a variety of atmospheric conditions. Several NATO Research Study Groups (RSGs) of the Defence Research Group (DRG)—especially the RSG on Optics and Infrared Technologies and the RSG on Maritime Remote Sensing—provide a potential mechanism for exchanges of fundamental scientific information in underlying phenomenologies of interest.

The Technology Cooperation Program (TTCP) provides a vehicle for a range of applicable exchange relating to both undersea systems and atmospheric propagation.

The CIS is most capable in some areas of the weapon-target environment (e.g., the theoretical and mathematical aspects of underwater acoustics). The United States and Western Europe lead in the tactical employment of environmental products due to a technological lead in high performance computers and related software and hardware.

DoD capabilities in weather forecasting exceed those of the CIS for most of the globe. For example, U.S. tropical cyclone forecasting capabilities far exceed those of the CIS. However, in the Arctic, a more significant region tactically, Russian knowledge of weather exceeds that of the United States because of greater experience, better facilities (such as ice-breaking ships), and a broader research base.

With increasing reliance on satellite-based remote sensing, technologies for improved collection and integration will advance and proliferate. Increasing interest has been noted on the part of such countries as Japan, China, India, and Brazil to deploy and operate their own remote sensing satellites. These are generally lower resolution (100+ meter) multi-spectral systems that fall below the 10-meter resolution of the French SPOT system. They represent a significant advance in domestic capability for these nations.

The Services have a number of exchanges, primarily in NATO but also with a few other friendly nations, in areas of specific interest. Predominant among the areas represented by these exchanges are oceanography, undersea acoustics, and atmospheric effects on IR sensors and propagation.

Commercial and academic interchanges with foreign counterparts play a significant role in transfer of technology and information related to remote sensing and environmental data and models. These interchanges are important means by which foreign military organizations keep abreast and upgrade their use of the environment and remote sensing capabilities.

Table 6-6. Summary and Comparison — Environmental Effects

Subarea	NATO Allies	Japan	CIS	Others
1. Environmental Sensing	□□□ O	□□□ O	□□ –	
2. Environmental Characterization and Prediction	□□□□ O	□□□ O	□□ –	
3. Scene Generation and Environmental Decision Aids	□□□ O	□□□ –	□□ –	
Overall[a]	□□□ O	□□□ O	□□ –	

[a] The overall evaluation is a subjective assessment of the average standing of the technology in the nation (or nations) considered.

LEGEND:

Position of other countries relative to the United States:

- □□□□ Broad technical achievement; capable of major contributions
- □□□ Moderate technical capability; possible leadership in some technical niches; capable of important contributions
- □□ Generally lagging; may be capable of contributing in selected areas
- □ Lagging in all important aspects; unlikely to contribute prior to 2002

Trend indicators—where significant or important capabilities exist (i.e., 3 or 4 blocks):

- \+ Foreign capability increasing at a faster rate than the United States
- O Foreign capability increasing at a similar rate to the United States
- – Foreign capability increasing at a slower rate than the United States
- ? Currently unable to assess rate of change in foreign capability vs. the United States

F. FUNDING

Table 6-7. Funding by Subarea ($ in Millions)

Subarea	FY92	FY93	FY94
Environmental Sensing	49	55	55
Environmental Characterization and Prediction	197	208	216
Battle Scene Generation and Environmental Decision Aids	112	106	92
TOTAL	358	369	363

Table 6-8. Funding by Program Element ($ in Millions)

PE No.	Title	FY92	FY93	FY94
0601102A	Defense Research Sciences	14.0	14.0	14.0
0601102F	Defense Research Sciences	20.0	22.0	21.0
0601153N	Defense Research Sciences	126.0	133.0	137.0
0602101F	Geophysics	37.0	41.0	43.0
0602435N	Ocean and Atmospheric Support Technology	45.0	49.0	50.0
0602784A	Military Engineering Technology	17.0	19.0	21.0
0603215C	Limited Defense System	86.0	78.0	63.0
0603410F	Space Systems Environmental Interactions	5.0	4.0	4.0
0603707F	Weather Systems - Adv Dev	6.0	6.0	6.0
0603734A	Military Engineering Advanced Technology	2.0	3.0	4.0
	TOTAL	358.0	369.0	363.0

7. MATERIALS AND PROCESSES

A. DESCRIPTION OF TECHNOLOGY AREA

1. Scope

The DoD Materials and Processes technology area spans the spectrum of structural, thermal protection, non-structural, and electronic materials. The scope of the program includes processing of advanced metal alloys (aluminum, steels, titanium, magnesium intermetallics); semiconductors, superconductors, optical materials and magnetic materials; polymers; property measurements/characterization/database; coatings; corrosion; nondestructive inspection/evaluation; fracture analysis/test; welding/joining; structural analysis/demonstration/test; survivability (including battle damage repair); erosion resistant, high temperature antenna windows/radomes/IR domes; supportability, etc. A large part of the program is directed at composite materials (organic, metal, ceramic, and carbon matrix) for aircraft, ships, submarines, land vehicles, missiles, and gas turbine applications. Other portions of the program are dedicated to protection/hardening of personnel/sensors/canopies/structures against hostile threats, such as laser weaponry. Cost-effective, integrated manufacturing technology is implicitly included in each of the above materials areas.

2. Materials and Processes Technology Subareas

a. Structural Materials, Processing, and Inspection

This subarea includes synthesis, processing, and characterization of all metallic and non-metallic materials and composites for application below 1000 °F with the primary purpose of load bearing and/or mechanical support for all classes of military vehicles, weapons, and non-vehicular structures. It also encompasses procedures, equipment, and sensors used to verify the quality of materials during processing and manufacturing and to detect and characterize failure-causing defects in systems in the field.

b. High Temperature and Anti-Armor Materials

This subarea includes synthesis, processing, and characterization of monolithic and composite materials and coatings for applications in propulsion, power, and vehicle structures where the essential material characteristic is the ability to withstand service temperatures greater than 1000°F and/or high strain rates. The latter condition particularly applies to materials for armor-defeating applications such as kinetic energy penetrators, sabots, warheads, and launcher systems or guns.

c. Electromagnetic and Armor Protection Materials

This subarea incorporates synthesis, processing, and characterization of those materials whose purpose is to protect personnel and system equipment against performance degradation or physical damage caused by laser or radio-frequency weapons and by kinetic energy or shaped charge projectiles. This category includes protection against lightning, electromagnetic pulse and electromagnetic interference damage.

d. Electronic, Magnetic, and Optical Materials

This subarea encompasses growth, processing, and characterization of advanced semiconductor materials to support electronic device technology; nonlinear optical materials for wavelength conversion, information processing and beam steering; superconducting materials for electronic, sensor, antenna, and power applications; electromagnetically transparent materials for radio frequency, infrared and visible bands; and magnetostrictive/electrostrictive materials for actuator, sensor, sonar and radar applications.

e. Special Function and Biomolecular Materials and Processes

This subarea includes synthesis, processing, and characterization of materials for applications such as fire retardation, coating and cleaning, lubrication, elastomeric sealants, and chemical and biological warfare protection. While not highly visible, this class of materials is critical to the performance, reliability, and maintainability of military systems. This category also includes the young but highly promising technology of synthesizing materials (such as polymers and membranes) by biologically derived processes (such as fermentation) and altering or destroying materials by biodegradation and bioremediation processes.

3. Assessment

The DoD Materials and Processes technology enables every system that flies, navigates on land or water, and shoots or is shot at as well as the infrastructure of surveillance, command, control, communications, intelligence, personnel well-being, and logistics. The conduct of this technology has two major thrusts: The Services, closely coordinated by the Technical Panel for Advanced Materials (TPAM) of the Joint Directors of Laboratories (JDL), address the major needs and opportunities that are readily identifiable for current and future military operations, and the Defense Advanced Research Projects Agency (DARPA) conducts a program of comparable size that is concentrated in a few high risk areas considered to offer very high potential payoff for future military systems. Since the DARPA projects are generally managed by the most appropriate Service, transitions to application occur readily.

a. Structural Materials, Processing, and Inspection

Structural materials include aluminum alloys, titanium alloys, steels, and organic matrix composites. They are used for structures that must function at temperatures under about 1000 °F and for which the important material characteristics are strength, stiffness, and fracture toughness. The bulk of all aircraft, tank, ship, submarine, and armament structures fall in this category. An assessment of the present trend in R&D goals would indicate that they are focused on decreasing weight and cost. One of the most successful lightweight structural composites, graphite fiber reinforced epoxy, has become widely used in advanced aircraft.

b. High Temperature and Anti-Armor Materials

This category of materials includes superalloys, refractory metals, ceramics, and a range of metal, ceramic and carbon matrix composities which can be used at high temperatures (greater than 1000 °F) or under severe loading conditions. Carbon-Carbon (C-C) composites, for example, retain their mechanical properties at temperatures approaching 3000 °F and thus they have long been targeted for use as gas turbine hot section blades and vanes. Oxidation is the major technical C-C problem, however, and efforts to alleviate this have been under way for the last 10 years. A combination of coatings and additives has been found to protect the C-C at 2500 °F for up to 100 hours which is long enough for expendable engines applications. Problems with manufacturing reliability and cost exist.

c. Electromagnetic and Armor Protection Materials

Recent program assessments have uncovered deficiencies in tri-Service/DARPA funding for protection capabilities against proliferated low-energy lasers operating in-band to eye and sensor wavelengths. In the past several years, dependence on the ability to see and operate in all mission scenarios, particularly at night, has increased substantially. At the same time, laser device technology has made dramatic strides in achieving low cost, wavelength agility, power efficiency, and packaging. These devices, operating in-band to eyes and sensors, have the ability to jam and/or damage eyes and sensors at extended ranges (2 to 8 km). Even small, commercially available lasers, intended for laboratory use, are readily adaptable to military use and are available to all third world countries. The tri-Service/DARPA technology program to provide hardening options has not been able to keep pace with laser device development. For threats where the laser produces several simultaneous wavelengths or possesses wavelength agility, protection options either provide damage protection only (with significant operator penalty and mission denial) or are not available at all.

d. Electronic, Magnetic, and Optical Materials

While the common perception of this class of materials concentrates on the growth and characterization of semiconductors, much of the materials R&D involves ceramics, either as substrates for thermal management of multichip modules; windows for IR; visible or microwave transmission; magneto-/electro-strictive transducers; or high-temperature superconductors.

e. Special Function and Biomodular Materials and Process

The goals of this class of materials are broad and include such unsung but vital aspects as sealants, coatings, cleaners, lubricants, and hydraulic fluids. It is perhaps in this area, more than the others, that future work on DoD environmental issues will take place. New biodegradation processes are expected to be especially important.

B. TECHNOLOGY AREA GOALS

Table 7-1. Materials and Processes Technology Goals

Subarea	By 1995	By 2000	By 2005
Structural Materials Processing and Inspection	• 20% decrease in Al aircraft and missile structures weight. • Zero CTE composite for spacecraft use.	• 800 °F Al alloys for engine components. • 40% reduction in cost of fibers for metal-matrix composites.	• Smart structure for in-service self-inspection of structural damage.
High Temperature and Anti-Armor Materials	• 30% wt. reduction in gas turbine blades/ discs. • 20% decrease in W penetrator cost.	• 2800 °F materials system for turbine components. • 50% reduction in cost of carbon-carbon composites for structural use.	• 1600 °F Ti composite for hypersonic airframes.
Electronic, Magnetic and Optical Materials	• Tenfold reduction in chip rejection rate. • Threefold increase in erosion resistance of EM transparencies.	• Development of photonic circuit materials immune to EM jamming. • Tenfold increase in radiation hardness of microelectronic mat'ls.	• Superconducting devices with tenfold power decrease. • 1000 °F micro-processor operating temperature.
Special Function and Bio-Molecular Materials	• Chlorofluoro-carbon substitute. • Environmentally benign coatings for corrosion protection.	• 50% cost reduction of fire-resistant hydraulic fluids. • 700 °F-capable elastomeric seals.	• >1200 °F lube for advanced turbine engines.
Electro-Magnetic and Armor Protection Materials	• Extend laser protection systems to night use. • 40% increase in capability of ceramic armor materials.	• Agile/broadband protection for IR/radar systems. • 50% reduction in ceramic armor cost.	• Composite armor materials for 16-ton, air-droppable vehicle.

C. RELATIONSHIP OF TECHNOLOGY GOALS TO THRUSTS

Table 7-2. Relationship of Materials and Processes Technology Goals to Thrusts

Thrust \ Subarea	Structural Materials, Processing, and Inspection	High Temperature and Anti-Armor Materials	Electromagnetic and Armor Protection in Materials
1. Global Surveillance and Communications	• 40% decrease in space-craft structure weight • Zero Coefficient of Thermal Expansion (CTE) composite for spacecraft	• 50% reduction in cost of C-C spacecraft structure	• Protection of sensors against agile laser threat
2. Precision Strike	• 20% decrease in cruise missile structure weight	• 2500 °F materials for cruise missile engines	• Laser protection for night use
3. Air Superiority and Defense	• Self-inspecting aircraft structure • 800° F Al alloys for engines	• 2500 °F materials for A/C turbine engines • 1600° F Ti composite for airframes	• 40% increase in capability of ceramic lightweight armor
4. Sea Control and Undersea Superiority	• 15 dB torpedo noise reduction	• Ultra-light refractory metal torpedo warheads	N/A
5. Advanced Land Combat	• 50% increase in fracture toughness of high strength steel	• 20% decrease in W penetration cost • 30% wt. reduction in gas turbine blades/ discs	• Protection of eyes and sensors against agile lasers • Composite armor materials
6. Synthetic Environments	N/A	N/A	N/A
7. Technology for Affordability	• 50% decrease in cost of A/C structure • Automated welding for ship fab, and repair	• 50% reduction in cost of C-C spacecraft structure	• 50% decrease in composite armor fabrication cost

(Continued)

Table 7-2. (Continued)

Thrust \ Subarea	Electronic, Magnetic, and Optical Materials	Special Function and Bio-Molecular Materials
1. Global Surveillance and Communications	• Superconducting circuit materials. • 50% reduction in reject rate wafers.	• 100% increased bearing life for pointing mechanisms. • Coating for corrosion protection.
2. Precision Strike	• Photonic circuit materials. • 3-fold increase in rain and dust resistance of radomes.	• >100 °F lubricant for cruise missile turbine engines.
3. Air Superiority and Defense	• 1000 °F operating temperature of micro processors.	• 700 °F capable aircraft sealants CFC substitute.
4. Sea Control and Undersea Superiority	• Advanced sonatransducer materials.	• Fire tolerant composite structures.
5. Advanced Land Combat	• Tenfold reduction in resistive electrical power consumption. • Tenfold increase in electronic radiation hardness.	• Increased sensivity chemical/biologist agent sensors.
6. Synthetic Environments	• Superconducting circuit components with 10x speed and 0.1 x power.	N/A.
7. Technology for Affordability	• Tenfold reduction in substrate and wafer rejection rate.	• 50% cost reduction of fire resistant hydraulic fluid.

D. SUBAREA ROADMAPS TO REACH TECHNOLOGY GOALS

Table 7-3. Roadmap of Technology Objectives for Structural Materials, Processing, and Inspection

Technology Set	By 1995	By 2000	By 2005
Aluminum Alloys	• Develop isotropic Al-Li alloys 30% stronger and 20% lighter than 7075 for aircraft structural application.	• High strength corrosion resistant aluminium for P31 torpedo.	• High temperature, 900°F, aluminum transferred to IHPTET for Phase III engine demo.
Steels	• Aeromet 100 available for aircraft structural and armor demonstration.	• High strength (>130 ksi) steel and joining processes for fabrication and repair of ship and land vehicles.	• Intergranular stress corrosion resistance to Aeromet 100 doubled.
Composites	• Precision metal and organic composites demonstrated on spacecraft structure.	• Fire tolerant load bearing organic matrix composite demonstrated on land and sea vehicles.	• Full-scale demonstration of "Smart" structure for in-service self inspection for structural damage.
	• 700 °F resin composite structures demonstrated for missiles, engines, and airframes.	• 40% reduction in cost of organic matrix composites attained.	• 800 °F organic matrix composite demonstrated for low cost expendable engine hardware.
	• Pilot-scale line to demonstrate 40% reduction in metal matrix composite cost.	• 50% increase in compression properties of metal-polymer hybrids for lightweight landing gear.	

Table 7-4. Roadmap of Technology Objectives for High Temperature and Anti-Armor Materials

Technology Set	By 1995	By 2000	By 2005
Metals	• 1400 °F titanium composites and intermetallics for Phase II IHPTET. • 2000 °F single crystal NiAl turbine blades in engine test. • Dual alloy turbine disks transitioned to IHPTET Phase II.	• 1600 °F titanium based composites for Phase III IHPTET. • Ultra-high strength steel for enhanced ASW defeat demonstrated. • Ballistic parity of tungsten and depleted uranium demonstrated.	• Titanium based IHPTET materials scaled-up for demonstration in hypersonic aircraft structure. • Depleted uranium penetrators completely replaced by tungsten.
Carbon-Carbon	• Oxidation resistant structural carbon-carbon demonstrated.	• High rate process line in-place for 50% decrease in manufacturing cost of carbon-carbon.	• Structural carbon-carbon demonstrated in IHPTET Phase III. • Components and light-weight spacecraft structure.
Ceramics	• 2800 °F capable ceramic reinforcing fiber feasibility demonstrated. • Ceramic matrix composites transitioned to F100 nozzle.	• 2500 °F ceramic components and thermal barrier coatings for diesel engines. • 2500 °F ceramic composite components demonstrated in IHPTET Phase II.	• 2800 °F cooled ceramic composite components on test in Phase III IHPTET. • >1000 °F ceramic bearing transitioned to turbine engine manufacturers.

Table 7-5. Roadmap of Technology Objectives for Electronic, Magnetic, and Optical Materials

Technology Set	By 1995	By 2000	By 2005
Semiconductors (III-V and GpIV materials)	• Repeatable growth of 4" dia. low dislocation GaAs. • Advanced manufacturing, in-line inspection, and process control for tenfold reduction in chip rejection rate.	• 2" dia. SiC boule to enable >1000 °F electronic devices.	• Distributed on-engine high temperature electronic controls for IHPTET Phase III. • Bulk InP ion implementation technology transitioned to devices.
High Temperature Superconductors (HTS)	• Demonstration of HTS magnets. • Demonstration of HTS interconnects and high speed switches.	• Introduction of HTS devices into cryoelectronics. • Demonstration of HTS motor with tenfold reduction in power requirements.	• Integration of HTS devices with high mobility semiconductors and magnetic circuit elements for tenfold increase in rad hardness.
Non-Linear Optical Materials	• 10-Watt output $ZnGeP_2$ demonstrated over 2.5 to 6 μm wavelength.	• Ferroelectronic thin film spatial light modulators demonstrated.	
Electromagnetic Transparencies	• Scale-up of ceramic materials and coatings for threefold increase in erosion resistance.	• High temperature canopy material for F22/ MRF demonstration.	• Full-scale diamond coated multi-mode transparency demo.
Magnetic and Electro-/ Magnetostructive Materials	• Non-volatile magnetic memory elements for rad hard data storage.	• Spin tunable magnetic semiconductor devices demonstrated.	• Processing procedures for integration of strictive materials into adaptive composites.

Table 7-6. Roadmap of Technology Objectives for Special Function and Bio-Molecular Materials

Technology Set	By 1995	By 2000	By 2005
Fluids and Lubricants	• Technology demonstration of corrosion-inhibited brake fluid completed. • Solid MoS_2 ion beam deposited spacecraft lubricant demonstration on-orbit.	• Pilot line to demonstrate 50% cost reduction of fire resistant hydraulic fluid.	• >1200 °F lubricant demonstrated on IHPTET Phase III. • Grease life of land systems extended beyond overhaul cycle.
Elastomeric Materials	• Demonstration of flexible chemical barrier coatings for protective garments.	• 700 °F elastromer for advanced engines and aircraft.	• Demonstration of acoustically transparent sonar array seals.
Coating Materials	• Complete test and evaluation of environmentally benign corrosion inhibiting coatings.	• New environmentally compatible coating systems transitioned to OEM and repair depots.	
Cleaning Materials	• Complete test and evaluation of chloroflourocarbon (CFC) substitutes for aircraft maintenance.		
Bio-Molecular Materials	• Tubule encapsulated anti-fouling coating feasibility demonstrated for ships.	• Fibers from silk protein scaled-up for armor applications.	• Bio-remediation of GaAs from discarded circuit boards.

Table 7-7. Roadmap of Technology Objectives for Electro-magnetic and Armor Protection Materials

Technology Set	By 1995	By 2000	By 2005
EM Protection Materials	• Rugate and/or holographic filter processing for night protection against fixed wavelength lasers.	• Non-linear optical materials developed for night protection against agile wavelength lasers.	• Devices deployed for sensor/eye protection against all laser damage and jamming threats.
Armor Materials	• Ballistic performance of Aeromet 100 optimized and integrated into aircraft armor. • 40% increase in capability of ceramic armor materials.	• 50% cost reduction in SiC and TiB_2 and full-scale process line for armor tile. • 30% decrease in composite armor fabrication costs. • 15% increase in resistance of steel armor to shear/plugging.	• 16-ton composite armored, air-droppable fighting vehicle demonstrated.

E. R&D IN OTHER ORGANIZATIONS (GOVERNMENT, INDUSTRY, FOREIGN)

1. Government

Government-wide coordination of DoD programs is accomplished through the Office of Science and Technology Policy Committee on Materials (OSTP/COMAT), which includes all federal agencies involved in materials research. Of special importance is the DoD participation with 10 other federal agencies in the government-wide Advanced Materials and Processing Program (AMPP). This program coordinates all of the federal agency materials R&D activities under the Federal Coordinating Council on Sciences, Engineering, and Technology (FCCSET) umbrella. It is the first fully coordinated approach to national materials R&D by the federal government.

For many years, the DoD and NASA have jointly supported the National Academy of Sciences (NAS)/National Materials Advisory Board (NMAB). This group conducts comprehensive studies of defense-related materials R&D issues. Many of those studies are of interest to other federal agencies which are encouraged to participate in the deliberations.

2. Industry

The growing concern over global competition, combined with reductions in defense procurements, has stimulated the U.S. materials industry to place greater emphasis on advanced materials research and development. It is estimated that large U.S. industry corporate investment in materials research and development more than matches the federal government investment of about $1.4 billion. Both large and small U.S. companies are also aggressively pursuing federal and state government contractual relationships which probably amounts to about one-half of the total government funding ($0.7 billion). Small companies, not having the internal resources to invest, have aggressively pursued the Small Business Innovative Research (SBIR) program to the extent that about 20 to 25 percent of the total federal government Phase I awards (and many Phase II ones) are advanced materials related. This amounts to about $40 to $50 million per year.

Much emphasis is being placed on low cost manufacturing processes as an essential route to commercialization and survival. The U.S. materials industry is also gradually shifting its emphasis from a long range DoD specific orientation to such programs as The National Aeronautics and Space Administration (NASA) High Speed Civil Transport (HSCT), High Temperature Engine Materials Technology Program (HiTemp), and

Enabling Propulsion Materials (EPM) programs as well as the Department of Energy (DoE) Continuous Fiber Ceramic Composite (CFCC) and Ceramic Turbine programs because of the potential for high volume commercial applications. Also being pursued are the Department of Commerce (DoC)/National Institute of Standards and Technology (NIST) Advanced Technology and Intelligent Processing of Metal Powders programs, both of which have high volume potential. For the DoD the U.S. materials industry is aggressively pursuing manufacturing technology and Title III programs, as well as the Defense Advanced Research Projects Agency (DARPA) pre-competitive technology insertion and partnership programs. This gradual shift of emphasis is all part of industry's drive towards lower cost manufacturing and commercialization of DoD-initiated materials technology.

The U.S. materials industry is also undertaking a number of strategic company-to-company (including foreign organizations) alliances of a variety of shapes and forms. Examples are the relationships between DuPont and the French SEP company, the alliances between British Petroleum (BP) and Atlantic Research Corporation (ARC), AMERCOM, and Carborundum, the arrangement between the Canadian ALCAN and Dural Composites, to cite only a few. The National Aero Space Plane (NASP) industry-led materials consortium composed of the NASP principal contractors led the way to the formation of the Great Lakes Composite Consortium (GLCC) and subsequently to the industry-funded Automotive Composites Consortium. Extensive use of Polymer Matrix Composites (PMCs) by the automotive industry would bring about completely new industries, including a comprehensive network of PMC repair facilities, molding and adhesive bonding equipment suppliers, and a recycling industry based on new technologies. Current steel vehicle recycling techniques will not be applicable to PMCs and cost-effective recycling technologies for PMCs have yet to be developed. This could be an industry itself. Numerous other industry groups are being formed to cover many other technical areas. The alliances have considerably strengthened U.S. industry's ability to compete in the global marketplace.

The U.S. materials industry has also undertaken an aggressive activist role to bring issues relating to their industry to the attention of government officials in both executive and legislative segments of the government. Industry groups such as the Suppliers of Advanced Composites Materials Association (SACMA), U.S. Advanced Ceramics Association (USACA), the Aerospace Industries Association (AIA), Integrated Dual Use Commercial Companies (IDCC), the Metal Powders Industries Association (MPIA), and others have been formed to collectively provide inputs about the business situation and offer legislative suggestions. More recently, professional societies such as the American

Society of Metals (ASM) and the Federation of Materials Societies (FMS) have taken on the responsibility of representing their members to the government.

In a parochial sense, the necessity for U.S. industry to compete worldwide has served to strengthen the DoD Materials and Process Technology programs. Instead of heavy dependence on government contractual funding to conduct materials R&D, U.S. industry is bring its own resources (both financial and business related) to strengthen its technology base. The industry emphasis appears to be towards shorter range goals at the expense of superior performance. The balance is maintained through the strong DoD Materials Research (6.1), University Research Initiative (URI), and DoE research programs which are rapidly being allied with industry through industry/academia arrangements.

3. Foreign

Although many industrialized countries have developed noteworthy metallurgical research and development capabilities, rigorous applications for the resulting achievements represents the most exacting technological challenge. For powder metallurgy (PM) and for dense alloys (DA), the United States is the world's leader, followed by (in alphabetical order) France, Germany, Japan, India, and the Commonwealth of Independent States (CIS) for PM, and by Austria, France, Germany, Israel, Sweden, the U.K., and CSI for DA. World capabilities in these areas can be attributed to a growing, broad range of industrial applications (aircraft, automotive), and these capabilities will continue to expand. Further development of individual capabilities in a specific metallurgical system, alloy, or production process will be associated more with the intended application. The U.S. is the world's leader in aluminide intermetallic compounds, driven by aircraft and propulsion applications; however, the CIS must also be recognized for their excellent accomplishments in this technology. The U.S., Japan, the U.K., France, and Germany are leaders in non-composite ceramic materials.

Worldwide activities in composites are generally related to both fiber and matrix supply, and to development/manufacturing of composite components for high performance military aerospace applications, sporting goods, and various commercial components. The high performance organic and carbon matrix composite area is dominated by France, Japan, and the U.S., followed by (in composites) Canada, Germany, Spain, the U.K., and CIS. There is a wide distribution in levels of this capability, but the overall capability for the highest quality/performance material resides in the three Western countries. The metal matrix area is dominated by the United States with Japan, the U.K., and CIS following in individual elements. France, Japan, and the U.S. provide world leadership in ceramic matrix composites, followed by the CIS and China.

Polymeric materials exploit the most sophisticated and technologically advanced areas of specialized chemistry. Development and production of these leading edge materials evolve in countries with a specific requisite scientific and industrial base. Even in the leading countries, the industrial base consists of a limited number of industrial concerns with extensive research, development, and specially designed production facilities. World leadership in both non-fluorinated and fluorinated materials resides in the U.S. but Japan is not far behind. The chemical industries in France, Germany, the U.K., Italy, Switzerland, CIS, and India provide capabilities in some critical areas.

The United States is the world's leader in high relative permeability sheet, with three major producers. Germany, France, Japan, and the U.K. have extensive capabilities, developed principally through high tonnage p[illegible]n of less developed materials used for ground fault interruptors. Less devel[illegible] capabilities exist in Austria, Canada, China, Czechoslovakia, Hungary, Israel, [illegible]y, [illegible]uth Korea, Romania, Sweden, South Africa, Taiwan, and CIS. Limited capability exists in India and Spain. In magnetostrictive alloys, the U.S. is the world's scientific leader; it has two producers, active actuator programs, and built transducers. France, Germany, Israel, Japan, the U.K., and CIS have a considerable number of scientific publications. However, France also has developed transducers, and the U.K. produces alloys for commercial applications. Germany, Sweden, and Japan have active actuator programs. Research activities on magnetostrictive alloys exist in Australia, Canada, China, Italy, Poland, and Spain.

The United States and Japan are world leaders in magnetic amorphous alloy strip and wire, respectively. Germany has extensive production capabilities, while China, France, the U.K., and CIS have some capabilities. Overall, major capability is centered in the U.S. and Japan.

Multifilamentary niobium-titanium (Nb-Ti) superconductor cables and wires are manufactured by a number of countries. The U.S., U.K., Japan, Germany, and Italy are probably the world leaders in this technology in terms of R&D, extensive conductor fabrication capabilities, and commercial supplies of this type of conductor. Other countries having some capabilities for fabricating certain types of Nb-Ti conductors include the Netherlands, India, France, Finland, and Austria. Countries such as Austria, Brazil, Canada, South Korea, the People's Republic of China (PRC), Switzerland, and Taiwan have fabricated samples of this material. Brazil, which has the largest known deposits of niobium ore, is believed to have initiated a program to fabricate Nb-Ti conductor. The CIS, on the other hand, is known to have some capability to fabricate Nb-Ti conductor but not at the same level as the U.S., U.K., Gennany, Japan, or Italy. There is some capability in former Warsaw Pact countries such as Poland, Hungary, and Czechoslovakia. In addition, the Finnish company Quotokumpo, a commercial copper conductor manufacturer, has some capabilities for preparing Nb-Ti conductors of acceptable quality and quantity.

In the case of superconductors with transition temperatures between 9.85 °K and 24 °K, namely niobium-tin and vanadium-gallium, the leading countries are the U.S. and U.K. in terms of R&D and fabrication of conductors for application, while Japan, Netherlands, and Germany have fabricated limited quantities of this type of conductor. There have been published reports describing the fabrication and evaluation of conductors of this type from Austria, Czechoslovakia, Canada, PRC, France, India, Finland, Italy, South Korea, Poland, Sweden, Switzerland, and Taiwan. The CIS is believed to have capabilities comparable to those of this latter group of countries but decidedly far behind the capabilities of the U.K. and U.S.

Table 7-8. Summary and Comparison — Materials and Processes

Subarea	NATO Allies		CIS [a]	Others
1. Structural Materials, Processing, and Inspection	☐☐☐○		☐☐☐	☐☐ China, India, Israel, S. Korea, Switzerland, Sweden
2. High Temperature and Anti-Armor Materials	☐☐☐○	☐☐○	☐☐☐	☐☐ Austria, Israel, Sweden
3. Electromagnetic and Armor Protection Materials	☐☐☐○	☐☐○	☐☐☐☐	☐☐ China, Israel
4. Electronic, Magnetic, and Optical Materials	☐☐☐○	☐☐☐☐○	☐☐	☐☐ Australia, China, India, S. Korea, Sweden, Switzerland
5. Special Function and Biomolecular Materials and Processes	☐☐☐○	☐☐☐○	☐	☐☐ Austria, China, Switzerland
Overall[b]	☐☐☐○	☐☐☐○	☐☐☐	☐☐

[a] As of dissolution, current rate of progress impossible to determine.

[b] The overall evaluation is a subjective assessment of the average standing of the technology in the nation (or nations) considered.

LEGEND:

Position of other countries relative to the United States:

- ☐☐☐☐ Broad technical achievement; capable of major contributions
- ☐☐☐ Moderate technical capability; possible leadership in some technical niches; capable of important contributions
- ☐☐ Generally lagging, may be capable of contributing in selected areas
- ☐ Lagging in all important aspects; unlikely to contribute prior to 2002

Trend indicators—where significant or important capabilities exist (i.e., 3 or 4 blocks):

- \+ Foreign capability increasing at a faster rate than the United States
- ○ Foreign capability increasing at a similar rate to the United States
- − Foreign capability increasing at a slower rate than the United States
- ? Currently unable to assess rate of change in foreign capability vs. the United States

F. FUNDING

Table 7-9. Funding by Subarea
($ in Millions)

Subarea	FY92	FY93	FY94
Structurai Materials Processing and Inspection	101	98	103
High Temperature and Anti-Armor Materials	74	70	70
Electromagnetic and Armor Protection	78	74	73
Electronic Magnetic and Optical Materials	79	80	81
Special Function and Bio-Molecular Materials	62	59	60
TOTAL	394	381	387

Table 7-10. Funding By Program Elements
($ In Millions)

PE No.	Title	FY92	FY93	FY94
0601101E	Defense Research Sciences	59.9	51.3	55.6
0601102A	Defense Research Sciences	13.3	13.1	12.9
0601102F	Defense Research Sciences	1.8	1.1	2.1
0601152N	In-House Independent Laboratory Research	0.7	0.7	0.2
0601153N	Defense Research Sciences	9.4	9.8	10.4
0602102F	Materials	46.1	55.3	52.8
0602105A	Materials Technology	8.8	9.4	10.3
0602111N	Anti-Air Warfare/Anti-Surface Warfare Technology	1.0	1.0	1.0
0602121N	Surface Ship Technology	2.0	1.0	1.1
0602203F	Aerospace Propulsion	0.4	1.1	0.9
0602211A	Aviation Technology	2.1	2.3	2.5
0602234N	Systems Support Technology	34.5	29.5	28.3
0602301E	Strategic Technology	82.9	82.9	82.9
0602303A	Missile Technology	0.7	1.1	1.0
0602314N	ASW Technology	1.7	2.7	2.7
0602601A	Combat Vehicle and Automotive Technology	4.8	3.4	2.6
0602602F	Conventional Munitions	0.2	0.1	0.0
0602616A	Fuze Technology	0.4	0.4	0.4
0602618A	Ballistics Technology	0.1	0.1	0.1
0602624A	Weapons and Munitions Technology	1.8	3.1	3.1
0602702F	Command, Control, and Communications	1.3	1.3	1.4
0602706A	Chemical/Biological Defense and Gen Investigation	0.5	0.5	0.4
0602709A	Night Vision Technology	1.3	1.2	0.4
0602712E	Materials and Electronics Technology	60.0	51.2	55.7
0602730A	Cold Regions Engineering Technology	0.1	0.1	0.1
0602786A	Logistics Technology	5.1	4.9	5.7
0602936N	Independent Exploratory Development	0.1	0.1	0.1
0603001A	Logistics Advanced Technology	1.0	1.4	1.4
0603005A	Combat Vehicle and Automotive Advanced Technology	0.0	0.5	1.0
0603013N	Gusty Badger	2.0	2.0	2.0
0603102A	Materials and Structures Advanced Technology	0.0	0.4	0.4
0603112F	Advanced Materials for Weapon Systems	20.0	19.8	20.1
0603211F	Aerospace Structures	1.4	0.3	0.0
0603214C	Space-Based Interceptors	2.8	2.8	2.8
0603217C		13.2	13.2	13.2
0603217F	Advanced Aircraft Systems	0.3	0.0	0.0
0603218C	Research and Support Activities	2.8	2.8	2.8
0603218F	High By-Pass Turbo Fan CX-HLS	0.4	0.1	0.0
0603224F	Close Support Fighter	0.3	0.0	0.0
0603502N	Surface Mine Countermeasures	0.6	0.0	0.0
0603612N	Joint Tactical Directed Energy	1.7	2.6	2.6
0603706N	Medical Development	0.4	0.4	0.4
0603710A	Night Vision Advanced Technology	0.8	0.7	1.1
0603801A	Aviation-Advanced Technology	3.7	3.6	2.6
0605502F	SBIR	1.1	1.0	1.0
0708011F	Industrial Preparedness	0.4	0.9	1.2
	TOTAL	393.9	381.2	387.3

8. ENERGY STORAGE

A. DESCRIPTION OF TECHNOLOGY AREA

1. Scope

To fulfill its mission, virtually every modern weapon system is highly dependent upon the performance characteristics of its energy storage system. As a result of the multiplicity of Navy, Army, and Air Force applications involving a wide variety of mission profiles, there are diverse requirements which dictate the use of multiple energy storage systems, such as high energy density propellants and explosives, batteries, and capacitors. These systems must be highly reliable and safe and must meet stringent performance requirements. Reductions in size, mass, sensitivity to environmental stimuli, and cost—with improved energy density, electrical efficiency, and reliability—are desired characteristics of the systems employing the new technologies.

2. Energy Storage Technology Subareas

a. Energetic Materials

The purpose of many weapons systems is to deliver an explosive-filled warhead or a kinetic energy projectile to a target. The propellant, pyrotechnic, and explosive systems must work reliably to deliver and detonate the warhead. Higher energy density materials increase the stand-off distance from which a munition may be launched or increase the lethal radius of a warhead.

b. Power Conditioning

Capacitors, inductors, switches, and high voltage rotating machines are the enabling technologies used in a wide range of weapon applications. Included are capacitor technologies for high pulse repetition frequency energy storage subsystems, like those used to power electric guns.

c. Energy/Power Sources

Battery technology provides portable power for three basic functions essential to the DoD: propulsion of vehicles and weapons, electric power for communication devices and weapon systems, and stand-by or emergency electrical power for equipment such as computers and electronics. The development of high energy (and power) density batteries is the major technology challenge in this area. Other concerns are cost, user safety, and benign environmental effects. Controlled chemical energy release systems store non-detonable fuel separate from a non-detonable oxidizer because they are highly reactive when combined.

3. Assessment

a. Energetic Materials

Energetic materials research programs are structured to (1) acquire the basic knowledge to design insensitive, powerful energetic materials; (2) formulate and test less sensitive energetic materials: (3) develop and demonstrate insensitive, low signature, high energy propellants; (4) develop and demonstrate high energy, low vulnerability gun propellants; (5) develop and demonstrate high energy, less sensitive explosives for shaped charges and explosively formed penetrators; (6) develop and demonstrate safe, dispersable explosives for minefield clearance; (7) develop and demonstrate insensitive high bubble energy underwater explosives; and (8) develop safer, lower cost processing techniques for energetic materials which are amenable to good quality control.

Propellants, Explosives, and Pyrotechnics. A variety of explosive types are being developed to provide munition developers with options for defeating a wide range of air and surface targets.

Hard target penetrator munitions of the Precision Strike Thrust require very insensitive explosives with high energy for fragmentation and blast. Such explosives are required by munitions that must penetrate bunkers, hulls, armor, or other obstructions before detonating. The major issue is achieving a balance between insensitivity and performance of the explosives.

Requirements for missile warheads to take advantage of advances in guidance and control and fuzing technologies are driving explosive development towards pliable explosives compatible with directional ordnance. Insensitivity to stresses from the deformation system is required for an explosive that will also provide maximum fragment energy.

Underwater explosives constitute a special class of materials designed to control the timing of energy release. Sometimes late energy release is necessary to form an oscillating bubble, while at other times early energy release is necessary to produce maximum shock through the water and into the target. Work is near completion on an explosive which will enhance bubble performance, giving torpedoes single shot kill capability where multiple torpedoes are currently needed to sink the target. As a result of concern about neutralizing surf zone mines, underwater explosives that will provide superior shock wave energy from configurations such as line charges, cords, or arrays are being developed.

Controlled Chemical Energy Release. For reasons related to power and safety, some propulsion systems are better served by propellants whose fuel and oxidizer are stored separately, rather than by faster burning propellants that contain explosives. The Navy is using a Stored Chemical Energy Propulsion System (SCEPS) in its newest torpedo. This is an example of a controlled chemical energy release system. SCEPS uses lithium as a fuel and fluorine compounds as the oxidizer. A more efficient system that will use water as the oxidizer is now in development.

b. Power Conditioning

Power conditioning is used to transform the source energy into a form that can be used by the weapon system. Some power conditioning systems convert the energy from the source (DC or AC) to the required supply, usually raising the voltages or currents by using transformers, voltage regulators, DC to DC converters, and other electrical devices. However, most power conditioning systems used for military applications are part of a pulsed power system and are referred to as pulse forming networks (PFN). The PFN transforms the source energy (DC or AC) into a specific pulse with either high voltage, high current, or both high voltage and high current. The PFN shapes the high-power pulse with capacitors, inductors, switches, and nonlinear elements and couples it to the load. A description of some of these critical elements is provided.

Capacitors. Capacitors are one of the enabling technologies for high pulse repetition frequency energy storage subsystems, like those used to power electric guns. The capacitors in the pulse forming network of pulsed power systems are used as both energy storage and pulse forming devices. The capacitor is charged from the prime power source, stored, and then released over a short time interval (e.g., several milliseconds, depending upon the mission), resulting in a high power, short duration pulse. Capacitors developed under the Balanced Technology Initiative (BTI)/Army Pulse Power Module (PPM) program (Joint Army/Navy ET Gun Project) represent the state of the art for production capacitors—1.5 kJ/kg energy density in an 85 kJ can. A subscale capacitor developed under the Mile Run program (a Joint Service/DNA program) achieved 2.7 kJ/kg.

The BTI/Army PPM and the DNA capacitor development work are the most significant achievements in power technology to date. Multi-shot ETC guns now have the ability to emerge from the laboratory and move onto the nation's ranges and proving grounds.

Inductors. Inductors are key elements in most PFNs which operate in the inductive energy storage mode. The energy stored in the capacitors is rapidly discharged through an inductor to form the pulse shaping required by using a resistance/inductance/capacitance RLC circuit. The energy is then trapped in the inductor and discharged to the load using an opening switch. Therefore, minimizing the size and volume of the inductors is essential to the total system weight reduction.

Switches. New technologies are leading to high power transfer, high action closing/opening switches for electrified weapon applications including electro-thermal-chemical (ETC), electromagnetic launchers (EML), and coilguns. In the present BTI/Army pulse power module, a megajoule class spark gap is being used repetitively, with success, at the highest power levels of any millisecond switch known.

Rotating Machines. Rotating electrical machines are being developed to provide the pulse power required for electric guns. The state of the art for rotating electrical machine is 1 kJ/kg, which is the capability of the most compact existing pulse power supply: a homopolar generator/inductor combination.

Energy densities of 10 kJ/kg are required for many applications. An Army/DARPA initiative toward compact power technology brought the state of the art from 0.2 up to 2 kJ/kg several years ago, using a homopolar generator/inductor combination for single shot rep-rates. Fabrication of a small rep-rated compulsator power supply which delivers 3.6 kJ/kg has been completed. Concepts involving new geometries and higher rotational speeds exist to raise this density by a factor of 5.

c. Energy/Power Sources

The Navy needs high power and high energy primary batteries for sonobuoys, unmanned underwater vehicles (UUVs), and torpedoes used in shallow coastal water. The Navy also needs large-size, high power, rechargeable batteries having higher energy density than silver/zinc to increase the range of underwater vehicles. The Army requires advanced rechargeable technology for advanced communications, electronics, and night vision equipment. The Army also needs rechargeables for such C3I uses as jammers, artillery direction, and target acquisition and high power rechargeables for electric weapons. Very large, high energy density rechargeable batteries are also required by the Air Force to replace lead acid batteries for missile silo emergency power, maintenance-free aircraft batteries, and onboard satellite batteries.

B. TECHNOLOGY AREA GOALS

Table 8-1. Energy Storage Technology Goals

Subarea	By 1995	By 2000	By 2005
Energetic Materials	• Mk 80 bombs to meet insensitive munition requirements. • Demonstrate explosive for large distributed arrays to clear mine-field path. • 50% increase in bubble energy of current explosives.	• Increase range of missiles by 20% at constant propellant weight and volume. • 100-200% increase in hard target penetrating warhead. • Manportable quick response rocket-launched system to deploy arrays. • Reduce processing hazards by 500%.	• Evaluate metastable materials to quadruple payload. • Manportable concrete and armor penetrating warhead. • Reduce processing cost and pollution by 50%.
Power Conditioning	• ETC guns for artillery and naval applications.	• EM gun for artillery and medium caliber application.	• EM gun for tank application.
Energy/Power Sources	• Extend satellite life by 7 years • Increase speed and range for underwater vehicles. • Increase communications battery life by 300% • Increased stealth and vehicle range. • Greater shallow water buoy performance. • Improve sonar countermeasures.	• More missions before battery replacement. • Longer use man portable electronics. • Buoy with maximum flexibility. • Empowered combat soldier. • Increase undersea surveillance capability by 50%. • Low cost, high energy undersea vehicle battery.	• Moldable to conform to soldier system or vehicle shape. • Increased survival time for missile silo power. • Develop [illegible] roving sh[illegible] countermeas[illegible] • Reduce [illegible] satellite [illegible]%. • Double surveillance capability. • Improve land mine target detection.

C. RELATIONSHIP OF TECHNOLOGY AREA GOALS TO THRUSTS

Table 8-2. Relationship of Energy Storage Goals to Thrusts

Thrust \ Subarea	Energetic Materials	Power Conditioning	Energy/Power Sources
1. Global Surveillance and Communications			• Enhanced satellite life with 50% reduction in battery weight and volume. • Portable communications. • Double operation life.
2. Precision Strike	• 100% increase in hard target penetration. • 50% increase in anti-ship probability of kill.	• ETC guns for artillery and ship gun extended range.	• Enhanced target detection. • Power for laser initiation of warheads. • Advanced fuze sensitivity to penetration • Increased ICBM payload volume.
3. Air Superiority and Defense	• Extend missile range by 50%. • Aimable warheads with 100% increase in kill probability.	• ETC for ship defense. • Direct energy system for missile defense.	• Establish UAV capability. • Improved missile guidance and control. • Reduced aircraft battery maintenance • Reduced silo power maintenance.
4. Sea Control and Undersea Superiority	• 50% improvement in underwater warhead probability of kill. • Shallow water mine neutralization. • Insensitive munitions.	• Torpedo electromagnetic ETC launchers. • Electric-drive torpedoes.	• Enhanced surveillance and reconnaissance system capability. • Establish underwater and surface zone countermeasure capability. • Double range for UUVs. • Stealth torpedo capability. • Reduced submarine maintenance. • High energy thermal propulsion systems.
5. Advanced Land Combat	• Extended range, reduced signature artillery.	• ETC/EM gun launch of hypervelocity projectiles.	• Enhanced land attack vehicle range. • Hypervelocity projectile launcher power.
6. Synthetic Environments	• Target interaction lethality/vulnerability modeling.		
7. Technology for Affordability			

D. SUBAREA ROADMAPS TO REACH TECHNOLOGY GOALS

Table 8-3. Roadmap of Technology Objectives for Energetic Materials

Technology Set	By 1995	By 2000	By 2005
Reduced Signature Propellant	• Achieve hazard class 1.1 performance with 1.3 propellant.	• No visible contrail signature while extending range by 200 nm over all other known anti-air missiles.	• Reduce IR signature by factor of ten.
High Energy Gun Propellant		• Increase range by 2 km and muzzle velocity by 200 m/s.	• 50% increase in mass impetus.
Non-Polluting Propellant	• Assorted concept evaluations.	• Eliminate launch site contamination.	• Double current performance with non-polluting fuel.
Shaped-Charge Explosive	• Demonstrate explosive with detonation pressure in excess of 450 Kbar.	• Demonstrate shaped charge with 20% more steel penetration than one using HMX.	
Insensitive Bomb Fill Explosive	• Develop explosive with 20% more internal blast than explosive in Tomahawk reactive case warhead which passes insensitive munition tests failed by Tomahawk warhead.	• Demonstrate bomb with Mk 80 performance which passes sympathetic detonation test.	• Demonstrate bomb with 20% more performance than Mk 80 which passes all insensitive munition tests.
New Underwater Explosive	• Demonstrate explosive with 50% more bubble than best underwater explosive in use in 1990.	• Demonstrate enhanced bubble explosive which passes insensitive munition safety tests.	• Explosive using metal-sea water reaction to produce twice as much damage producing energy.
New Melt Cast Explosive	• Demonstrate explosive with 50% higher detonation pressure than TNT .	• Demonstrate shaped charge with 50% more steel penetration than Comp B shaped charge.	• Laboratory demonstration of pilot plant procedure for manufacturing explosive costing less than HMX.
Continuous Processing		• Demonstrate initial feasibility of continuous processing to reduce hazards by 500%.	• Demonstrate a 50% reduction in processing costs and environmental pollution.

Table 8-4. Roadmap of Technology Objectives for Power Conditioning

Technology Set	By 1995	By 2000	By 2005
Rotating Machines	• Delivered energy of 3 kJ/kg.	• Delivered energy of 10 kJ/kg.	• Delivered energy of 12 kJ/kg.
Capacitors	• Delivered energy of 9 kJ/kg.	• Delivered energy of 15 kJ/kg.	• Delivered energy of 18 kJ/kg.

Table 8-5. Roadmap of Technology Objectives for Energy/Power Sources

Technology Set	By 1995	By 2000	By 2005
High Energy Rechargeable Batteries	• For Navy vehicles, increase energy density from 120 Whr/kg to >220 Whr/kg. • For Army vehicles, increase energy density from 40 Whr/kg to >100 Whr/kg. • 20-year maintenance-free aircraft battery.	• Double number of cycles ($50 \rightarrow 100$). • Reduce cost to $3/Whr. • Extend low earth orbit satellite life by >7 years. • AF/Navy, advanced satellite power at 50% weight reduction.	• Develop all solid-state battery with volume reduction of 50%. • Replace primary satellite batteries with long life rechargeables. • Satellite battery weight reduction by achieving 220 Whr/kg.
High Power, High Energy Non-Rechargeable Batteries	• For Navy vehicles, increase power density from 45 W/kg to >1000 W/kg.	• For Navy sonobuoys, increase energy density by 8; increase power density by 2.	
Low Power, Long Life Non-Rechargeable Batteries	—	• For Navy, deliver >2 W for 1 year at ≤50 lb.	• For Navy, deliver 5 W for ≥2 yrs at ≤75 lb.
High Power Rechargeable Batteries	• For Army vehicle launchers, high power to 100 W/kg.		
High Energy Thermal Propulsion Systems	• Demonstrate hydrox-powered, half-length torpedo in water.	• Demonstrate very long range propulsion system for UUVs.	

E. R&D IN OTHER ORGANIZATIONS (GOVERNMENT, INDUSTRY, FOREIGN)

1. Government and Industry

Some energetic materials R&D is done within the United States, outside DoD. The Department of Energy weapons laboratories are the other primary sources for explosives R&D. Propellant R&D is done by the DoE laboratories as well as private propellant manufacturers (e.g., Aerojet, Hercules, Thiokol). American universities are funded by the Service basic research offices to do synthesis studies and develop diagnostic techniques. The Service efforts are well coordinated with the DoE laboratories and propellant manufacturers through such mechanisms as DoD Information Analysis Centers; Joint Army, Navy, NASA, Air Force (JANNAF); and DoD/DoE Memorandums of Understanding.

The advent of modern high-energy beam weapons concepts, such as high-power lasers, particle beam weapons, electromagnetic guns, and high-power microwaves, increased interest in power conditioning systems. Work on these devices is research oriented, and major reductions in the size and weight of the associated power systems are required. In the current environment, the organizations supporting the military's power programs are research or university oriented. The commercial power industry provides some support. Potential manufacturing technologies of interest include solid-state and gas discharge switches of the opening and closing type, inductive storage devices, capacitors, batteries and homopolar generators, and compensated alternators.

The United States is the world's leader in the development of compact, lightweight power systems for a variety of applications. In the power conditioning field, effective two-way exchanges exist. Initiatives from the Japanese, the Soviets, the Israelis, the British, and the Germans are planned or under way on a small scale.

High energy capacity/high rate batteries have a potential role in Strategic Defense Initiative test beds and as components of operational systems. Inter-Service and Inter-government coordination of battery research, development, and engineering is accomplished through the Interagency Power Sources Symposium, workshops, and technical exchange conferences.

2. Foreign

Ongoing international research and development in the subareas of Energetic Materials and Power Conditioning indicates that these may be international capabilities to help meet the following challenges and goals:

- Improved properties of insensitive high explosives.
- Reduced observable signatures of propellants while maintaining or improving performance.
- Improved modeling of energetic material reactions (three-dimensional, combined mechanical/chemical reaction properties).
- Application of energetic materials to ballotechnic processing.
- Reduction in size and mass of power systems and components by an order of magnitude.
- Development of photo-conductive and solid-state switches.
- Development of high power microwave (HPM) sources.
- Development of continuous processing techniques.

The United States has the lead in the development of certain chemical explosives; however, countries such as France and the U.K. have the ability to match our accomplishments and can incorporate these materials into weapons as quickly, if not more quickly, than the United States. For example, both France and the U.K. have now synthesized CL-20, which was first synthesized in the United States in 1987. And advanced HEDM work will offer primary opportunities for cooperation with France and the U.K.. Most other countries are not assessed to be actively engaged in the development of new explosives or higher energy density materials beyond the current production state-of-the-art materials such as RDX and HMX.

Production technology for most common energetic materials, such as nitroglycerine, nitrocellulose, and TNT, is widely available from a number of countries throughout the world. Certain countries, such as Italy and Switzerland, have an acknowledged lead in the production of nitroglycerine. The raw materials for the manufacture of these materials are widely available in every country with an established chemical process industry. At the present time, the French and British appear to have programs to develop new generations of HEDMs that are similar to chemicals currently under development and certification in the United States. These materials are approximately 20 percent more energetic than RDX and appear to have acceptable shock sensitivity and related parameters. There have not been any noticeable development efforts in other countries (allied or friendly) that would indicate a comparable program at this time; however, this assessment is based more on a lack of confirming data than specific data. France and the United States are very active in continuous processing and are actively cooperating.

Development of energetic materials for both liquid- and solid-fueled missiles and rockets is widespread throughout the world. The French are now publishing their own textbook for the design and formulation of fuels for missiles, a clear indication of their progress in the missile age. Japan, Israel, France, the U.K., Australia, Sweden, Norway, Canada, Germany, Italy, Switzerland, the Republic of Korea, Taiwan, Indonesia, India, and Pakistan all have programs for the development of solid-fueled and/or liquid-fueled engines for missiles and rockets. The relative accomplishments of these countries varies from state of the art to primitive. At this time, however, the rate of advance is very rapid, and each of these countries has access to all of the necessary infrastructure and technological support to develop state-of-the-art HEDM, comparable to many currently under R&D programs in the United States.

The former Soviet states—i.e., the Commonwealth of Independent States (CIS)—have an extremely large R&D program for the development of HEDM which in some respects is more advanced than that in the West. In fact, the CIS have made investments in several areas for which comparable programs do not exist in the West. In particular, the CIS is perceived to be ahead of the United States in the areas of insensitive high explosives development and ballotechnic formulations.

Concerning the subarea of Power Conditioning, the United States is the undisputed free-world leader in the development of compact, lightweight power systems for a variety of applications. Recent breakthroughs in U.S. capacitor fabrication (increasing energy densities by an order of magnitude) have established a significant U.S. lead in this key niche technology. However, the CIS has an extensive program in pulsed power (e.g., using pulsed magnetohydrodynamics) and may possess a lead in other areas.

Opportunities for cooperative research in pulsed power should no longer be limited to Western Europe and Japan in niche technologies relating to switching or specific applications, since cooperation with the CIS in explosive pulse power is now thought to be possible. In addition, there is potential for cooperation in a range of technologies that might be used as primary power for pulsed systems.

The CIS has developed high average pc ver repetitive pulsed power technology that is more portable than the U.S. equivalent. The CIS is the current leader in this field; in fact, it may well be in the lead in some key technology areas, parti ularly gaseous switching and inductive energy storage. In general, the CIS has developed explosive pulsed power technology far more extensively than has the U.S.

The United States is assessed to have a significant lead in the development of high efficiency space-qualified solar arrays, a candidate for a primary power source and a potential key element of an overall pulsed power system. The most advanced cells to date use GaAs technology, in which both Western Europe and Japan are active.

High energy capacity/high rate batteries have a potential role in SDI test beds and as components of operational systems. France has an active and broad-based program in both primary and secondary batteries and could potentially contribute to cooperative research in this area.

U.S. government funding for pulsed-power R&D is divided among the national laboratories, private industry, and universities. The same is generally true internationally, except in Japan. There, in addition to government-funded R&D in pulsed-power, Japanese industry is funding several university programs for developing repetitive electron and ion beams for materials processing. Japanese GaAs technology might also have potential future uses in active array pulsed microwave power generation.

In Germany, CIS, France, the U.K., and the PRC, the vast majority of pulsed-power research and development is funded by the government, using national laboratory and university components. Funding for military applications is generally level but with increasing funding for commercial applications.

Table 8-6. Summary and Comparison — Energy Storage

Subarea	NATO Allies	Japan	CIS	Others
1. Energetic Materials	□□□ O	□□ +	□□□ –	
2. Power Conditioning	□□□ O	□□ +	□□ –	
3. Power Sources	□□ O	□□□ O	□□□ –	
Overall [a]	□□□ O	□□ +	□□□ –	

[a] The overall evaluation is a subjective assessment of the average standing of the technology in the nation (or nations) considered.

LEGEND:

Position of other countries relative to the United States:

□□□□ Broad technical achievement; capable of major contributions

□□□ Moderate technical capability; possible leadership in some technical niches; capable of important contributions

□□ Generally lagging; may be capable of contributing in selected areas

□ Lagging in all important aspects; unlikely to contribute prior to 2002

Trend indicators—where significant or important capabilities exist (i.e., 3 or 4 blocks):

+ Foreign capability increasing at a faster rate than the United States

O Foreign capability increasing at a similar rate to the United States

– Foreign capability increasing at a slower rate than the United States

? Currently unable to assess rate of change in foreign capability vs. the United States

F. FUNDING

Table 8-7. Funding by Subarea
($ In Millions)

Subarea	FY92	FY93	FY94
Energetic Materials	19	20	19
Power Conditioning	9	12	15
Energy/Power Sources	19	21	20
TOTAL	47	53	54

Table 8-8. Funding by Program Element
($ In Millions)

PE No.	Title	FY92	FY93	FY94
0601153N	Defense Research Sciences	6.0	7.0	7.0
0602111N	Anti-Air Warfare/Anti-Surface Warfare Technology	0.1	0.3	0.3
0602203F	Aerospace Propulsion	4.1	1.5	1.5
0602234N	Systems Support Technology	0.4	0.4	0.4
0602302A	Next Generation Propellants	0.4	0.4	0.4
0602314N	ASW Technology	8.2	7.7	8.2
0602314N	High Energy Thermal Power Systems Project	4.7	3.1	5.8
0602602F	Conventional Munitions	1.7	1.9	2.3
0602618A	Ballistics Technology	1.8	1.8	1.8
0602624A	Weaoons and Munitions Technology	5.0	4.6	4.4
0602705A	Electronics and Electronic Devices	2.3	4.0	4.2
0602705N	Joint Army/Navy Lithium Ion Rechargeable Battery	0.5	0.8	0.5
0602715H	Defense Nuclear Agency	1.8	5.3	9.0
0602936N	Independent Exploratory Development	0.1	0.1	0.1
0603217C	IR Focal Plane Arrays	1.5	1.4	1.4
0603218C	Research and Support Activities	2.5	2.4	2.4
603609N	Insensitive Munitions Adv. Dev.	5.8	6.8	4.0
	TOTAL	46.9	52.5	53.7

9. PROPULSION AND ENERGY CONVERSION

A. DESCRIPTION OF TECHNOLOGY AREA

1. Scope

Propulsion and energy conversion technologies apply to all military combat vehicular systems, including aircraft, tactical and strategic missiles, space launch vehicles, space vehicles, future hypersonic systems, combat and amphibious vehicles, ships, and submarines and other underwater craft. The propulsion systems involved include: airbreathing types (based on gas-turbine, ramjet/scramjet, combined-cycle, diesel and rotary engines), fuel cells, and non-airbreathing types (based on solid rocket, liquid rocket, electric, solar, and nuclear sources). Energy conversion systems include solar to electric, electro-mechanical, direct thermal to electrical, and heat engines of various sorts.

Propulsion and energy conversion subsystems account for a significant fraction of the size, weight, and signature of vehicular systems. Accordingly, increases in range, payload, speed, stealth, and supportability and decreases in cost of either existing or new vehicular systems depend vitally on advances in propulsion and energy conversion technology. This broad, aggressive, and well-focused science and technology effort is essential to achieving the goals of the thrust areas and maintaining qualitative military superiority. Further developments are required in aerothermodynamics, high temperature/high strength/lightweight materials, hydrodynamics, structures, tribology, fuels and propellants, instrumentation, controls, and direct energy conversion phenomena.

2. Propulsion and Energy Conversion Technology Subareas

a. IHPTET

IHPTET is an integrated tri-Service/DARPA/NASA/Industry program aimed at doubling aircraft gas-turbine propulsion system capability by around the turn of the century for all DoD aircraft and cruise missile needs.

b. Missile, Space, and Aerospace Vehicle Propulsion

This subarea consists of efforts that address solid and liquid rockets for space launch and orbit transfer; ducted rockets, ramjets, scramjets, and compound-cycle engines for missile and aerospace vehicle applications; electrical, solar, and nuclear propulsion for orbit transfer applications; and the National Aero-Space Plane (NASP) program.

c. Surface/Undersurface Vehicle Propulsion

This subarea consists of efforts that address propulsion and ship service prime movers (primarily diesel and gas turbine) and power transmission (both electrical and mechanical) for all surface vehicles; nuclear power plants, associated propulsion machinery, and propulsors for submarines; and specialized propulsion systems for other underwater vehicles.

d. Energy Conversion/Power Generation

This subarea consists of efforts that address space and aircraft power generation systems, aircraft transmissions, and fuels and lubricants.

3. Assessment

a. IHPTET

The capability and cost of aircraft and cruise missile systems are directly dependent on the performance of the propulsion system, as evidenced by the fact that the propulsion system (engines plus fuel) accounts for 40 to 60 percent of the takeoff weight of aircraft. Potential payoffs in terms of unit capability are large: for example, achieving the IHPTET goals offers intercontinental range in an ALCM-sized missile, a fivefold increase in speed for tactical cruise missiles, a 100 percent increase in range/payload for both attack aircraft and helicopters, a sustained Mach 3+ capability in an F-15–sized aircraft, and greater range/payload capability in an F-18–sized STOVL aircraft.

Propulsion technology is important in determining the capability of upgraded systems as well as new systems as illustrated by the F-16: the original engine has had three major upgrades, a competitive engine has been introduced, and this latter engine has had a major upgrade. Given that aircraft-related expenditures account for approximately one-third of the DoD budget (or roughly $90 billion per year), achieving the IHPTET goals will significantly affect future military capability and costs. Accordingly, IHPTET is the highest priority effort in air-breathing propulsion technology.

Aircraft gas-turbine technology is also vital to the U.S. industrial base. The value of military and commercial shipments for the domestic aircraft gas-turbine manufacturers was approximately $21.6 billion in 1988, split about equally between military and commercial. Further, by virtue of the aircraft gas turbine's importance in determining the overall quality of aircraft, it is a major factor in the current favorable balance of trade in the aerospace sector. Because aircraft gas-turbine technology in generally applicable to both military and civil engines, achieving the IHPTET goals can ensure continued U.S. preeminence well into the 21st century.

b. Missile, Space, and Aerospace Vehicle Propulsion

System payoffs associated with the technology goals in this subarea are high. They include the potential of single-stage-to-orbit space launch operations with a significant decrease in payload cost to low earth orbit, a 100 percent increase in the no-escape zone for air-to-air missiles; long range Mach 5+ capability for surface-to-air missiles, a 200 percent increase in payload to geosynchronous earth orbit with no increase in launch system size, and much improved battlefield survivability.

Currently, the domestic industrial base in this subarea primarily serves DoD, DoE, and NASA; most non-military applications relate to NASA and communication-satellite-launch. The air-breathing portion of this subarea—primarily in hypersonic propulsion—can apply in part to high speed transports. Advances in materials and aerothermodynamic techniques can be expected to contribute significantly to a wide spectrum of the military and commercial industrial base.

c. Surface/Undersurface Vehicle Propulsion

The system payoffs associated with advanced technology in this subarea are significant. Smaller and lighter land combat vehicle power packages will enable 40-ton main battle tanks and more capable light combat vehicles. Increased efficiency gas-turbine and fuel-cell power plants, electric drives, and quiet propulsors will provide for increased range and/or reduced size and reduced signatures of naval surface combatants. And integrated propulsion/external hydrodynamics for submarines will increase covertness at reduced size and cost.

The domestic industrial base in this area is mixed; the market for engine manufacturers is dominated by other applications, both military and commercial; the market for nuclear propulsion plants, transmissions, and propulsors is relatively small and uniquely military. In the areas of diesel engines and fuel cells, technology advances can be expected to contribute to the commercial industrial base.

d. Energy Conversion/Power Generation

The system payoffs associated with advanced technology in this subarea are also significant, including 50 percent weight reduction of satellite payloads, greater survivability of satellites and aircraft, fuel cooling capacity adequate to sustain high Mach number flight, and reduced signature for undersea weapons.

The majority of efforts in this area can be expected to contribute to the domestic commercial industrial base. In particular, advances related to both satellite payloads and aircraft are largely common to their commercial counterparts.

B. TECHNOLOGY AREA GOALS

Table 9-1. Propulsion and Energy Conversion Technology Goals

Subarea	By 1995	By 2000	By 2005
IHPTET — Turbofan/Turbojet Engines	• +30% thrust/weight. • +100°F combustor inlet temperature. • -20% fuel burned (typical).	• +60% thrust/weight. • +200°F combustor inlet temperature. • -30% fuel burned (typical).	• +100% thrust/weight. • +400°F combustor inlet temperature. • -40% fuel burned (typical).
— Turboshaft/Turbo-prop Engines	• -20% SFC. • +40% power/weight.	• -30% SFC. • +80% power/weight.	• -40% SFC. • +120% power/weight.
— Expendable Engines	• -20% SFC • +35% thrust/airflow. • -30% cost.	• -30% SFC. • +70% thrust/airflow. • -45% cost.	• -40% SFC. • +100% thrust/airflow. • -60% cost.
Missile, Space, and Aerospace Vehicle Propulsion	• +100% total effective impulse for air-to-air missiles. • +100% specific impulse for low-thrust orbit transfer systems. • Insensitive propulsion for tactical missiles.	• Low observable, thrust-vectoring, air/ air propulsion. • Mach 0-5 combined-cycle engine. • +100% specific impulse for moderate- thrust orbit transfer systems.	• Ramjet/scramjet operation to Mach 15-20. • Mach 0-7 combined-cycle engine. • 30% payload increase, 25% cost reduction for ballistic missile propulsion. • +100% specific impulse for high- thrust orbit transfer systems.
Surface/Undersurface Vehicle Propulsion	• +100% in power density for land/ amphibious vehicle engines.	• Electric drives for land/amphibious vehicles and small surface combatants. • 40% reduced cost for quiet submarine propulsors.	• +100% in power density for land vehicle power packages. • Superconducting electric drives for ships. • High efficiency fuel cells for marine propulsion.
Energy Conversion/ Power Generation	• +50% in solar energy conversion efficiency. • Hardened solar-cell array. • +50% increase in JP-8 cooling capacity.	• -25% in weight, +100% in reliability in aircraft power systems. • +500% in hydro-carbon fuel cooling capacity.	• +100% in solar energy conversion efficiency. • -40% in space radiator weight. • -50% in weight, +200-400% in reliability in aircraft power systems.

C. RELATIONSHIP OF TECHNOLOGY GOALS TO THRUSTS

Table 9-2. Relationship of Technology Goals to Thrusts

Subarea / Thrust	IHPTET	Missile, Space, and Aerospace Vehicle Propulsion	Surface/ Undersurface Vehicle Propulsion	Energy Conversion/ Power Generation
1. Global Surveillance and Communications	• +100% increase in UAV endurance.	• 50-75% decrease in payload cost to LEO. • Factor of three decrease in GEO payload cost.	• Not applicable.	• Survivable satellites. • 50% reduction in satellite payload.
2. Precision Strike	• Tenfold improvement in missile reaction time and coverage. • +100% increase in range/payload for attack aircraft.	• Sustained Mach capability for extended range missiles. • Increased survivability due to insensitive missile propulsion.	• Not applicable.	• Enabler for sustained high Mach number vehicles. • Increased survivability and reduced maintenance for aircraft.
3. Air Superiority and Defense	• Sixfold increase in fighter aircraft kill ratio. • Sustained Mach 3 capability. • Affordable stealth.	• 100% increase in no-escape zone in air-air combat. • Long-range air defense.	• Not applicable.	• Increased survivability and reduced maintenance for aircraft.
4. Sea Control and Undersea Superiority	• Foundation for next-generation surface combatant power plants.	• Not applicable.	• Reduced signature for ships and underwater craft. • +40% ship range.	• Reduced signature for undersea weapons.
5. Advanced Land	• 100% increase in helicopter range/payload. • Enabler for 40-ton main battle tank.	• Increased survivability due to insensitive missile propulsion.	• Enables 40-ton main battle tank.	• Not applicable.
7. Technology for Affordability	• 20 to 30% reduction in aircraft fuel costs. • 50% reduction in aircraft engine maintenance costs. • 50% reduction in aircraft payload delivery costs.	• 50 to 75% reduction in payload cost to LEO. • Threefold decrease in payload cost to GEO.	• 30% reduction in ship fuel cost. • 20% reduction in armored vehicle fuel costs.	• 15% reduction in aircraft maintenance costs.

D. SUBAREA ROADMAPS TO REACH TECHNOLOGY GOALS

Table 9-3. Roadmap of Technology Objectives for IHPTET

Technology Set	By 1995	By 2000	By 2005
Compression Systems	• Metal matrix composites. • Swept aerodynamics. • 1300 °F. titanium/ titanium aluminide. • Hollow blades.	• 1500 °F titanium aluminide/MMC. • Brush seals. • Fiber-reinforced MMC ring rotors. • 3-D viscous CFD design.	• 1800 °F titanium aluminide/MMC. • All composite design. • Exoskeletal structure. • Max loading. • Active stabilization.
Combustion Systems	• Double dome/double wall liners. • Transpiration cooled augmentor liner. • 2200 °F ceramics. • High-temperature augmentor flameholder spraybar.	• Innovative dome concepts. • CMC augmentor liner. • 2400 °F ceramics. • Integrated augmentor/ nozzle. • Variable geometry fuel nozzles.	• Variable geometry flow configuration. • Integral design. • Non-metallic liners. • Titanium MMC cases. • Active combustion control.
Turbine Systems	• High effectiveness cooling. • 1850 °F disk super alloy. • High AN² rotors. • Ceramic blade outer air seals. • 2100 °F thermal barrier coatings.	• Improved cooling effectiveness. • 3-D viscous CFD design. • 2000 °F intermetallics. • Fiber-reinforced disk. • 2500 °F uncooled non-metallics. • 2500 °F thermal barrier coatings.	• 2800 °F cooled non-metallics. • 2500 °F intermetallics. • Composite cases. • Air leakage reduced 50%. • Lightweight static structures.
Exhaust Nozzles	• Pitch vectoring. • Composite liners. • Selective cooling. • 2500-2800 °F C-C structures.	• Pitch/yaw vectoring. • Titanium aluminide MMC structures. • Reduced cooling. • 2800 °F CMC panels.	• Full vectoring. • All-composite uncooled design. • 1800 °F titanium aluminide MMC. • Greater than 2800°F CMC/C-C.
Mechanical Systems	• 400 °F liquid/600 °F solid lube. • Intershaft bearings/ seals. • Advanced dampers. • 1000 °F limited life bearing.	• 600 °F liquid lube. • Advanced bearing/ seal/gear materials. • Advanced analytical tools. • 1500 °F limited life bearing.	• 700-800 °F liquid lube. • Advanced component materials. • Integrated mechanical system demonstration. • High modulus shafting.

Table 9-4. Roadmap of Technology Objectives for Missile, Space, and Aerospace Vehicle Propulsion

Technology Set	By 1995	By 2000	By 2005
Scramjet/Combined Cycle Systems	• Simulated low speed performance (NASP). • Scramjet performance demonstrated (NASP). • Wide Mach combustor demonstration (missile). • Improved efficiency combustor (missile). • 1400 °F hydrocarbon fuel heat exchanger (TRJ). • 2140 °F integrated ramburner spraybar/flameholder (TRJ).	• Flight demonstration of scamjet performance (NASP). • Solid fuel piloting concept (missile). • Variable geometry ramburner (TRJ). • Mach 5 freejet engine demonstration (ATR). • Improved mixer concept (ATR). • High temperature uncooled turbine (ATR). • Improved high efficiency combustor concept (ATR). • Transition valve mode change demonstration (TRJ). • 2000 °F CMC fan (ATR).	• Single-stage-to-orbit demonstration (NASP). • Mach 7+ freejet liquid fueled engine demonstration (missile). • 2000 °F fuel heat exchanger/reactor (TRJ/ATR). • Advanced ramburner fuel injector/flameholder (TRJ). • Duel mode turbo-scramjet burner Mach 7+ operation (TRJ). • 2500 °F fan (ATR). • 800 sec ISP solid fuel engine demonstration (ATR). • High energy density solid gas generator propellant (ATR).
Tactical Missile Propulsion	• Variable-flow ducted rocket. • Boron solid-fuel ramjet. • Mitigating composite cases for insensitive motors. • High density gelled fuel. • Signature prediction models.	• TVC low-drag ramjet concept. • Variable geometry low-drag ramjet inlet. • Flight-weight GAP ducted rocket. • Gelled liquid-propellant flight-weight motor. • Low plume signature solid-rocket motor demonstration.	
Space Vehicle and Ballistic Missile Propulsion	• Altitude compensating nozzle. • Fast-burn propellant. • Advance polymer processing for rocket motor cases. • Electronic propulsion for orbit transfer.	• Advanced polymer rocket motor case. • Advanced propellant/case bonding. • Solar propulsion for orbit transfer. • Cryogenic stored propellants for orbit transfer.	• Low cost ICBM propulsion techniques. • Nuclear propulsion for orbit transfer.

Table 9-5. Roadmap of Technology Objectives for Surface/Undersurface Vehicle Propulsion

Technology Set	By 1995	By 2000	By 2005
Power Plants	• Turborotocompound engine. • High temperature nitrogen-dispersion strengthened recuperator. • Room-temperature, direct-oxidation fuel cell. • Proton exchange membrane fuel cell.	• High temperature, low heat rejection diesel engine components. • High temperature synthetic lubricants for diesel engines. • Near-stoichiometric fuel burning techniques. • Aluminum-oxygen semi-cell.	• High power density engine for land combat vehicles. • High efficiency fuel-cell power for marine vehicles.
Transmissions	• Electric drive concept for land combat vehicles. • Composite shafting.	• Lightweight permanent magnet traction motors and alternators. • Lightweight, high power conditioning devices. • Cooling components for superconducting electric drives.	• Integrated electric drive subsystem for land combat vehicles. • Superconducting electric drive subsystem for ships.
Propulsors	• High efficiency water-jet system.	• Ultra-quiet propulsors for ships and submarines.	

Table 9-6. Roadmap of Technology Objectives for Energy Conversion/Power Generation

Technology Set	By 1995	By 2000	By 2005
Space Power	• High efficiency, multi-junction photovoltaic cells. • Thermionic converter—8% efficient with 1800 K emitter, 1070 K collector. • 5 kW survivable photovoltaic array (1000 W/kg). • Carbon/carbon composite radiator structures. • Metal-oxide-semiconductor controlled thyristor	• Lightweight, thin film photovoltaic cells. • 300 W/kg planar arrays. • Thermionic converter—10% efficient with 2000 K emitter, 880 K collector. • Advanced heat pipes and two-phase flow heat transfer systems. • Multi-stage Stirling cryocooler. • Lightweight, 95% efficiency power management and distribution components.	• High efficiency, spectrum-splitting photovoltaic cells. • 23% efficient thin film photovoltaic cells. • 600 w/kg planar arrays. • Thermionic converter—15-20% efficient with 2000 K emitter, 1200 K collector.
Aircraft Power	• Reliable variable speed, constant frequency generator. • MCT inverter. • 270-V DC system. • High heat flux power-electronics cooling.	• Integral engine starter/generator. • High stiffness electric actuators. • High power density auxiliary power unit. • Hybrid air/closed vapor cycle environmental control system (ECS).	• High frequency integral engine starter/generator. • High frequency electric actuators. • Integral engine emergency starter. • Electrically driven hybrid ECS.
Advanced Hydrocarbon Fuels/Systems	• Advanced JP-8.	• 2250 BTU/lbm cooling with JP fuel. • Advanced fuel system demonstration.	• 3000 BTU/lbm cooling with JP 900.

E. R&D IN OTHER ORGANIZATIONS (GOVERNMENT, INDUSTRY, FOREIGN)

1. Government and Industry

Both NASA and industry participate in the coordinated IHPTET program. For fiscal year 1993, related NASA IHPTET funding is approximately $30 million, and related industry discretionary funding is estimated to be approximately $125 million (the DoD request for direct IHPTET funding is $132 million). Related NASA activity is primarily directed at discipline research in high-temperature, lightweight materials and computational fluid dynamics. Each of the seven aircraft gas-turbine engine manufacturers maintains and executes their own IHPTET plan. All activities are coordinated through the IHPTET Steering Committee, chaired by DoD.

NASA conducts significant technology efforts in the area of missile, space, and aerospace propulsion, most notably in space launch propulsion and NASP (the latter is a joint DoD/NASA program). Related NASA funding in these areas for fiscal year 1993 is approximately $130 million. DoE conducts technology efforts associated with nuclear space propulsion. Industry conducts a broad range of technology efforts in this area, and their discretionary funding is estimated at $65 million in fiscal year 1993. Activities in this area are coordinated through the Joint Army, Navy, NASA, Air Force (JANNAF) Propulsion Committee.

In the area of surface and undersea vehicle technology, DoE conducts significant R&D programs in nuclear reactors and other prime-mover technology, and industry supports various efforts in these areas with discretionary funding.

NASA conducts extensive R&D related to space power systems, and DoE sponsors efforts related to photovoltaic conversion and thermionic energy conversion for terrestrial power generation purposes. Industry technology efforts in selected technologies are substantial, particularly in space and aircraft power systems.

2. Foreign

The U.S. continues to lead in the key aspects of gas-turbine engine technology, but the world's major industrial nations (most notably the U.K., France, Germany, Japan, and the CIS) are expected to pursue on a priority basis efforts to increase the capability of gas-turbine engines along lines similar to the IHPTET program. The worldwide commercial infrastructure for gas-turbine engine development and production is highly developed in many regions, and continues to expand. Increasing cooperation among the European Community nations could permit them to field a complete range of high-technology aircraft engines for military applications. French high-thrust commercial turbofans are based on a joint venture with a U.S. manufacturer, in which the low pressure/temperature components are made in France. The CIS possesses an extensive capability to field a complete family of aircraft engines, although their technological capability lags that of the U.S. Other technically emerging countries, such as China, Israel, India, Taiwan, and South Korea, are striving to achieve greater indigenous capabilities to produce a portion of their engine requirements.

The United States continues to be the preeminent manufacturer of aircraft gas turbines, but less so than in the past as measured by market share: the U.S. market has dropped from 84 percent to 62 percent over the last 20 years. Since industry financial support for U.S. technology development is derived from military and commercial sales, a strong U.S. market share is important to the health of the U.S. technology base. In general, principal cooperative opportunities could exist with NATO (especially with France, Germany, and the United Kingdom) and with Japan. To capitalize on the benefits of cooperative technology development, collaborative programs must have no negative effect on future U.S. market share.

The United States remains the leader in space vehicle propulsion technology, closely followed by the CIS. The CIS, with their extensive history in the development of storable-liquid rocket propulsion systems for strategic missiles, may hold a lead in this area. France and China have also demonstrated significant abilities to launch space payloads, and Japan has a range of space boosters and is developing a cryogenic hydrogen-oxygen engine. U.S. tactical missile rocket propulsion technology is approximately equal to that available in France, Japan, and the CIS. In hypersonic air-breathing propulsion, the U.S. continues to lead due largely to the NASP program, although France, Germany, Japan, the U.K., and the CIS are active in the area. The CIS's ramjet and scramjet developments are particularly noteworthy. Principal cooperative opportunities could exist with NATO (particularly France, Germany, and the U.K.), Japan, and the CIS.

The U.S. holds a leading position in nuclear propulsion for naval vessels. The CIS has been a risk taker in its efforts to increase the power output of their nuclear power plants for naval surface ship and submarine propulsion. Both limited core life and safety weaknesses have been characteristic, although improvements have been made over time.

In non-nuclear propulsion technology, the U.S. is generally on a par with other developed countries with the exception of signature reduction, in which the U.S. leads. A number of countries are active in the development of air-independent propulsion systems (e.g., diesel and Stirling engines and fuel cells) that may prove advantageous for smaller submarines. This includes Germany, Italy, the Netherlands, Sweden, Japan, and the CIS. In the total area of surface/undersurface vehicle propulsion, principal cooperative opportunities could exist with NATO (particularly France, Germany, and the U.K.), Japan, and the CIS.

The U.S. maintains a slight lead in comparison with other developed countries in most of the technology related to energy conversion and power generation; moderate power-level space power systems, aircraft power systems, and fuels are particularly noteworthy in this regard. By virtue of their large space program, the CIS have a strong position in the ability to address high electrical power requirements for satellite applications. These solar and thermionic power supplies have been accomplished through good engineering solutions that have overcome certain technical limitations. Japan and our NATO allies are considered to possess important niche technologies in the area. Principal cooperative opportunities could exist with NATO (especially France, Germany, and the U.K.), Japan, and the CIS.

Table 9-7. Summary and Comparison — Propulsion and Energy Conversion

Subarea	NATO Allies	Japan	CIS	Others
1. Aircraft Propulsion	□□□ O	□□	□□□ ?	□ China, India
2. Missile, Space, and Aerospace Vehicle Propulsion	□□□ O	□□□ O	□□□□ ?	□□ China, India
3. Surface/Undersurface Vehicle Propulsion	□□□ O	□□□ +	□□□ ?	□□ Sweden
4. Energy Conversion/Power Generation	□□□ O	□□ +	□□□ ?	
Overall[a]	□□□ O	□□□ O	□□□ ?	

[a] The overall evaluation is a subjective assessment of the average standing of the technology in the nation (or nations) considered.

LEGEND:

Position of other countries relative to the United States:

- □□□□ Broad technical achievement; capable of major contributions
- □□□ Moderate technical capability; possible leadership in some technical niches; capable of important contributions
- □□ Generally lagging; may be capable of contributing in selected areas
- □ Lagging in all important aspects; unlikely to contribute prior to 2002

Trend indicators—where significant or important capabilities exist (i.e., 3 or 4 blocks):

- \+ Foreign capability increasing at a faster rate than the United States
- O Foreign capability increasing at a similar rate to the United States
- — Foreign capability increasing at a slower rate than the United States
- ? Currently unable to assess rate of change in foreign capability vs. the United States

F. FUNDING

Table 9-8. Funding by Subarea
($ In Millions)

Subarea	FY92	FY93	FY94
IHPTET	136	142	139
Missile, Space, and Aerospace Vehicle Propulsion	161	183	181
Surface/Undersurface Vehicle Propulsion	38	43	38
Energy Conversion/Power Generation	69	82	72
TOTAL	404	450	430

Table 9-9. Funding by Program Element
($ in Millions)

PE No.	Title	FY92	FY93	FY94
0602102F	Materials	11.0	12.0	11.0
0602111N	Anti-Air Warfare/Anti-Surface Warfare Technology	5.0	4.0	4.0
0602121N	Surface Ship Technology	2.0	3.0	2.0
0602122N	Aircraft Technology	5.0	5.0	5.0
0602131M	Marine Corps Landing Force Technology	2.0	2.0	2.0
0602203F	Aerospace Propulsion	65.0	80.0	66.0
0602211A	Aviation Technology	4.0	4.0	4.0
0602234N	Systems Support Technology	3.0	3.0	3.0
0602302F	Rocket Propulsion	25.0	32.0	33.0
0602303A	Missile Technology	1.0	1.0	3.0
0602323N	Submarine Technology	3.0	3.0	3.0
0602324N	Nuclear Propulsion	12.0	16.0	17.0
0602601A	Combat Vehicle and Automotive Technology	2.0	2.0	2.0
0603003A	Aviation Advanced Technology	9.0	8.0	9.0
0603112F	Advanced Materials for Weapon Systems	3.0	1.0	2.0
0603202F	Aerospace Propulsion Subsystems Integration	29.0	29.0	27.0
0603211F	Aerospace Structures	2.0	1.0	1.0
0603215C	Limited Defense System	5.0	5.0	5.0
0603216F	Aerospace Propulsion and Power Technology	41.0	40.0	37.0
0603217C	IR Focal Plane Arrays	21.0	25.0	30.0
0603217N	Advanced Aircraft Subsystems	3.0	8.0	8.0
0603218C	Research and Support Activities	8.0	8.0	8.0
0603269F	National Aero Space Plane Technology	85.0	100.0	110.0
0603302F	Space and Missile Rocket Propulsion	14.0	16.0	10.0
0603313A	Missile & Rocket Advanced Technology	7.0	6.0	5.0
0603401F	Advanced Spacecraft Technology	13.0	9.0	6.0
0603640M	Marine Corps Advanced Technology Demonstration	1.0	1.0	3.0
0603790D	NATO Research and Development	4.0	7.0	2.0
060XXX1E	DARPA	3.0	3.0	3.0
060XXX2E	DARPA	16.0	16.0	9.0
	TOTAL	404.0	450.0	430.0

10. DESIGN AUTOMATION

A. DESCRIPTION OF TECHNOLOGY AREA

1. Scope

Design automation technology encompasses computer-aided design, integrated product and process development (concurrent engineering), and simulation and modeling, including the computational aspects of fluid dynamics, electromagnetics, advanced structures, structural dynamics, and other automated design processes. Design automation is designated as a key technology because it is critical to implementing the effective and efficient engineering process on which successful achievement of the goals of the Seven S&T Thrusts depends. Because design automation is a new DoD technology, neither the broad area nor the subareas have had a specific R&D focus.

Design automation provides the underlying technology necessary to develop the tools and integrating framework for concurrent engineering, cooperative design management, "virtual" factory and operation simulations, and design synthesis and reusable design libraries. It will be an indispensable part of the modern engineering process. Through the use of design automation, rapid prototyping can be carried out addressing hardware, software, packaging, manufacturing, and test. System life requirements can be evaluated under severe, simulated environmental conditions to determine the robustness of the design prior to the production decision. Design automation technology will provide common languages, tools, and metrics to reduce ambiguities in communications among the many contractors and DoD organizations who work together. This technology will facilitate exchange of design information created in many different engineering developments and, more importantly, provide the tools and descriptions to check consistency between specifications, design implementation, and simulated measured performance.

The major goal of design automation is to provide the engineer with the capability to simultaneously assess the design from a performance perspective and from a manufacturability and an operational life cycle standpoint. The engineer will then be able to implement the design into a physical hardware representation which optimizes the balance between system performance requirements, manufacturing costs, and operational and support characteristics. The objectives for this key technology area are:

- Unambiguous, easily transportable product descriptions
- Functional and feature based design
- High fidelity product visualization
- Product performance—supportability interaction.

By achieving these objectives the DoD will benefit through compressed development-to-deployment time; optimization of design for lowest product and operating costs; reduction of expensive hardware prototypes and laboratory and test facilities; delivery of higher quality equipment with robust performance, manufacturing, and operational suitability characteristics; a capability to conduct virtual prototyping; and a description of the design that can be used throughout the life cycle of the product for maintenance, design upgrades, and problem resolution.

2. Design Automation Technology Subareas

a. Design Synthesis and Analysis

Design synthesis and analysis supports the basic engineering activities necessary to design an effective system as well as synthesis tools which "create" preliminary designs at various levels of hierarchy. Modeling, simulation, and analysis techniques such as computational fluid dynamics, structural analysis, dynamic modeling, thermal analysis, finite element analysis, and other similar design tools play a key role in the basic engineering design process. The focus of design synthesis and analysis is on the engineering activities relating user requirements to alternative design solutions and their allocation to the physical world.

b. Product and Process Definition

Product and process definition addresses the engineering activities related to the physical implementation of the design and the interactions between the physical product and manufacturing or support processes. Technology thrusts in this subarea address such aspects of automated design as product definition exchange standards, functional and physical design languages, and associated modeling and simulation of processes.

c. Information Flow and Integration

Information flow and integration addresses the overarching issue of information flow and integration both within and among each of the above subareas as well as interactions external to the product. For example, the complexity of today's systems necessitates a multifunctional team approach to the design of not only the product but also its related manufacturing and support processes. The ability for each team member to participate in this multifaceted design process, in a real-time manner, requires effective information flow and integration among the team members and also among various information sources or data bases. The ability of the engineer to evaluate the representation of his product in simulated "real-world conditions" before the product is built will depend on the rapid evolution of information and networking technology. Activities such as integration of information systems, data base management, interface standards, and networking fall under the subarea of Information Flow and Integration.

3. Assessment

Investment in design automation technology will provide significant gains in the effectiveness of the computer-aided design and computer-aided engineering capabilities used in designing and manufacturing military weapon systems. Potential payoffs include product development time reduction as much as 60 percent; microelectronics fabrication process time reduction of up to 45 percent; field reliability improvements of up to 80 percent; fourfold enhancement in manufacturing yield; scrap and rework reductions of as much as 85 percent; and fifteenfold reduction in engineering changes per drawing, all of which translate into significant cost reductions. The implementation of design automation technology offers the potential to revolutionize the acquisition environment to effectively meet the challenges of today—the need to improve productivity, flexibility, use of capital, time to market, and product quality and reliability, at reduced costs.

In addition to these payoffs for individual system development, the introduction of standardized models and languages offers the potential to reduce costs of the logistic system by 25 percent. Data bases that can store descriptions and determine differences between components, if any, offer the potential for specifying a behavior that will allow spares to be stocked more efficiently and emulated in current technology when manufacturing sources become unavailable.

The design automation technology area is a binding technology. Because of the close relationship and influence it has on other key technology areas—especially software, computers, communications, networking, electronic devices, and human-system interfaces—it is crucial to recognize that many of the design automation activities will overlap and impact other technology areas.

Each of the S&T Thrusts will realize the gains made from investing in design automation technology. Thrust 7, Technology for Affordability, in particular will benefit because design automation technology will not only reduce unit and life cycle costs, but will also reduce the time required to transition technology into production. Design Automation provides the capabilities to design weapon systems that are cost effective, technologically superior, reliable, supportable, producible, and conducive to efficient upgrading.

B. TECHNOLOGY AREA GOALS

Table 10-1. Design Automation Technology Goals

Subarea	By 1995	By 2000	By 2005
Design Synthesis and Analysis	• Design analysis and simulation methods and tools that support all stages of the design process, addressing product and manufacturing and support processes.	• Computational prototyping linking product and process to reduce the need for actual physical prototyping.	• Concurrent analyses of product and processes, including functions, complexity, lead time, manufacturability, and field operations and support.
Product and Process Definition	• Behavioral representation of subsystem functional and physical characteristics.	• Standard, automated representation of subsystems in terms of conceptual design, functional and physical characteristics.	• Standard, automated linked system-subsystem descriptions based on functional and physical features.
Information Flow and Integration	• Capability to couple design with manufacturing and support process operations and constraints.	• Design knowledge data base, completely accessible to all engineering designers. • Capability to evaluate product performance in simulated usage environments.	• Realization of interactive, incremental, concurrent engineering of large-scale multidisciplinary designs by distributed teams. • Capability to evaluate interaction between product, process, and usage environment.

C. RELATIONSHIP OF TECHNOLOGY GOALS TO THRUSTS

Table 10-2. Relationship of Technology Goals to Thrusts

Thrust \ Subarea	Design Synthesis and Analysis	Product and Process Definition	Information Flow and Integration
1. Global Surveillance and Communications	• Reliable satellites. • Increased availability. • Greater performance.	• Lower cost through flexible manufacture. • Provides flexible architecture.	• Shorter development time. • Improved system documentation.
2. Precision Strike	• Reduced maintenance for aircraft. • Increased availability. • Greater performance.	• Improved design process for integrating components.	• Shorter development time. • Improved system documentation.
3. Air Superiority and Defense	• Reduced maintenance for aircraft. • Increased availability. • Greater performance.	• Increased worldwide supportability. • Reduced life cycle cost.	• Shorter development time. • Improved system documentation.
4. Sea Control and Undersea Superiority	• Reduced maintenance for ships. • Increased availability. • Greater performance.	• Advanced ship design process. • Lowest production and operating costs.	• Shorter development time. • Improved system documentation.
5. Advanced Land Combat	• Reduced maintenance for land systems. • Improved effectiveness. • Increased availability.	• Increased worldwide supportability. • Reduced life cycle cost.	• Shorter development time. • Improved system documentation.
6. Synthetic Environments	• Simulations based on real requirements.	• Virtual prototyping capability.	• Design and manufacture tradeoffs.
7. Technology for Affordability	• Decoupled cost and volume. • Reduced maintenance costs, longer product life.	• Integrated product and process development. • Higher confidence in requirements, performance, and projected manufacturing costs.	• Rapid, error-free transition to production. • Reduction in development time.

D. SUBAREA ROADMAPS TO REACH TECHNOLOGY GOALS

Table 10-3. Roadmap of Technology Objectives for Design Synthesis and Analysis

Technology Set	By 1995	By 2000	By 2005
Component Level	• Understand relationship between tolerance and cost. – Develop mathematical basis for tolerances • Microwave fault models diagnostic techniques.	• Methods for tolerance allocation. – Assess effect of tolerance on design parameters	• Design methods based on tolerance allocation to minimize influence of variation on the design.
Functional Group Level	• Refinement and development of numerical model. • Utilization of parallel computing. • Improved visualization techniques. • Visualization of complex data (such as fluid flow).	• Expanded use of parallel/distributed computing. • Ability to generate simulation tools from basic mathematics (shorten time to develop new simulation tools). • Microelectronic, analog/digital synthesis.	• Customizable computer processor for specific analysis problems.
System Level	Not applicable.	• Integration of different domains (thermal, fluid, stress). • Integration of different technologies.	• More complete models. – Nonlinear – Second and third order effects – Cross coupling effects – Automated analysis • Fundamental mathematics integration.

Table 10-4. Roadmap of Technology Objectives for Product and Process Definition

Technology Set	By 1995	By 2000	By 2005
Physical Implementation Prototyping	• Expand envelope of part types (size, shapes). • Increase accuracy of processes (control shrinkage, warpage). • Develop consistent geometric representation ability throughout product life cycle. • Multichip module packaging and interconnect CAD.	• Expand envelope of materials usage, allow for prototypes made with wide range of materials. • Allow for custom materials. • All designs based on single representation scheme (useful for all life cycle aspects).	• Customizable materials. • Integrate sensors and electronics with structural components. • Widespread use in production of small lots sizes. • Constraint management system incorporated into CAD and CAE. • Support for conceptual phase.
Process Prototyping	• Establish research programs to represent – different domains used in different models – behavior representation • Handle behavior modeling for individual part simulation of key environmental effects. • Reverse engineering. • Explore options at conceptual design.	• Formal models representing design decision, rationale, and constraints. • Trade off (cost vs. maintainability). • Integration with project management methods (Pert, Gantt charts). • Handle behavior modeling for subassemblies. • Simulation of all environmental effects and how to manufacture qualitative and quantitative models.	• Integration with CAD and CAE – Allow integration across life cycle – Cost analysis at all stages of design • Handle behavior modeling for entire product – Simulation of weapon systems in combat environments

(Continued)

Table 10-4. (Continued)

Technology Set	By 1995	By 2000	By 2005
Process Environments	• Characterization of requirements and models for – Assembly – Manufacturing – Maintenance – Cost – Test • Characterization of manufacturing process models – Understand primary parameters – Model parameters interaction • Characterization of design elements – form, fit, function	• Concurrent engineering techniques used for communications of all life cycle requirements during design phase. • Characterization of manufacturing process models – Understand primary parameters – Model parameters interaction • Mapping of function to specific design requirements.	• Develop methods for optimization of design for X methods/ optimization. • Ability to customize new manufacturing processes to – Control materials properties – Control interaction with other processes – Custom materials • CAD systems capable of performing detailed design for functional requirements.
Process Description Languages	• Level I and II implementation of PDES. • Full analog hardware descriptive language. • Formal verification using VHDL. • Device models for tubes.	• Electronic system design languages.	• Standard product data in wide use nationally, for all product designs.

Table 10-5. Roadmap of Technology Objectives for Information Flow and Integration

Technology Set	By 1995	By 2000	By 2005
Interface Definition	• Establish brokerage mechanism and communications infrastructure . • Improves sharing of design information. • Develop formal representation for decision including –constraints, issues –value assessment –trade-off –cost • Define data base models to support design, analysis, simulation, production, and life cycle support.	• Allow multivendor competition for design/manufacturing of components/ subsystems. • Broader access to best design and production. • Increased access to commercial base. • Create design languages for domains. • Decision support tools. • Demonstrate consensus/derived industry standard. • Distributed object-oriented data bases.	• Nationwide electronic infrastructure in place. • Brokerage for design, analysis,manufacturing, and service of major mechanical and electronic systems. • Develop formal semantic models for design methods. • Widespread use of design languages and integration with CAD & CAE environment. • Establish fully integrated weapons data base to facilitate design, procurement, manufacturing, training, repair, and overhaul.
Design Knowledge Architecture	• Catalogue of design knowledge –Handbooks –Corporate rules • MMACE system framework definition. • Library of on-the-shelf simulatable board modules system design.	• Computerization of a design knowledge. • Design languages. • MMACE tools and framework complete • MMACE validation and demo. • System design environment which optimizes design against constraints for software and VHDL models.	• Complete integration of design knowledge into CAD & CAE tools.
Protocols	• Develop concept of fully distributed, scalable communication networks serving manufacturing.	• Implement pilot programs of robust integrated networks.	• Implement seamless networking in defense and industrial base.

E. R&D IN OTHER ORGANIZATIONS (GOVERNMENT, INDUSTRY, FOREIGN)

1. Government and Industry

Design automation R&D activities can be found in other government organizations, throughout industry, and in the academic community. Industry is making large-scale investments in developing design automation capabilities as a principal business and as part of their basic business approach to remaining competitive in the U.S. and world marketplace. Separately there are government investments with industry; for example, NTIS is conducting related work under their Advanced Technology Program, specifically in the area of process and product time reduction. The academic community is becoming involved in developing design automation. A forerunner of the type of activity that is taking place in the academic community is the University of Maryland CALCE Electronics Packaging Research Center, which has the unique combination of university, government, and industry sponsorship. Languages for expressing design-related functional models and simulators are university products being funded by the DoD basic research program (6.1 R&D program category). Many of the electronic descriptive languages and analysis tools, such as VHDL and SPICE, were based on university work. Major efforts are under way at the university level to conduct fundamental research in advanced design automation techniques, sponsored by such organizations as DARPA, the National Highway Traffic Safety Administration, and the National Science Foundation. In addition, technical societies have focused their attention on design automation. The American Society of Mechanical Engineers (ASME) has established a technical group on design automation and sponsors an annual conference on the subject. The Institute of Electrical and Electronics Engineers (IEEE) also has a major element of its computer society involved in design automation.

2. Foreign

Cooperative opportunities will continue to exist with our NATO allies, especially the U.K., Germany, Canada, and with Japan; all of whom are assessed to have substantial programs in design automation. Considerable ongoing research and development in design automation indicates potential contributions to address such problems as: numerical techniques for the modeling of nonlinear processes for advanced computing architectures;

validating materials performance models (including the reaction of materials to extreme conditions); and other simulation of complex situations/environments.

Many Western European countries, though lagging in aspects of modeling, have led in producing the data needed for model validation and improvement (e.g. the U.K.'s research in chemical defense). Thus, important potential synergisms may exist between selected U.S. modeling communities and their experimental counterparts in other countries.

Secondary opportunities for cooperation exist in niche technologies related to modeling of nuclear and solar power (Italy) and modeling of particle accelerators. In addition, the widespread effort in algorithms for parallel processing, such as that in the Netherlands, may contribute to advances in numerical methods in computational fluid dynamics and hydrodynamic modeling. Other countries are active in modeling power and transportation systems.

Civilian simulation and modeling applications are being applied to a variety of complex systems, most notably power (including nuclear power as an important subset), transportation, and telecommunications. These areas can frequently prove to hold considerable military interest, especially in new software techniques.

Within NATO, the U.K. is active in a number of areas of interest, including computational fluid dynamics and modeling of complex communications networks. A number of other NATO countries have ongoing efforts relating to aspects of modeling spacecraft control and thermal management. Germany uses simulation to explore an automatic tactical fighter director with integrated fire-flight control systems for automated air-to-air combat and is active in simulation supporting the European Fighter Aircraft.

Japan's capabilities in computing and industrial process control offer promising cooperative opportunities. In general, however, Japan trails the U.S. in the development of validated engineering data bases for military systems that are required for effective modeling.

The CIS researchers have demonstrated a strong capability in modeling wave-flow dynamics and turbulence, and their data base for ocean simulation may lead those available in the United States. Russian researchers are very capable in the simulation and modeling of aviation and space systems. The United States maintains superiority with respect to data for purposes of modeling (prediction) and computational hardware and software for simulation and modeling.

The CIS used simulation and modeling extensively for weapon development. Though the Russians trail the United States in computational capabilities and the use of large-scale computers and graphic workstations, their strong mathematical skills and thorough understanding of the subject matter permits them to do some interesting modeling work. In some applications, such as wargaming, their knowledge base may equal or lead that of the United States.

Table 10-6. Summary and Comparison — Design Automation

Subarea	NATO Allies	Japan	CIS	Others [a]
1. Design Synthesis and Analysis	□□□ ○	□□	□□	□
2. Product and Process Definition	□□□ ○	□□□ +	□□□ ?	□
3. Information Flow and Integration	□□□ ○	□□□ ○	□□	□
Overall[b]	□□□ ○	□□□ ○	□□	□

[a] Several countries such as Israel, India, South Korea, Sweden, and Taiwan are working to advance their capabilities in design automation through a combination of purchases and indigenous development.

[b] The overall evaluation is a subjective assessment of the average standing of the technology in the nation (or nations) considered.

LEGEND:

Position of other countries relative to the United States:

- □□□□ Broad technical achievement; capable of major contributions
- □□□ Moderate technical capability; possible leadership in some technical niches; capable of important contributions
- □□ Generally lagging; may be capable of contributing in selected areas
- □ Lagging in all important aspects; unlikely to contribute prior to 2002

Trend indicators—where significant or important capabilities exist (i.e., 3 or 4 blocks):

- \+ Foreign capability increasing at a faster rate than the United States
- ○ Foreign capability increasing at a similar rate to the United States
- — Foreign capability increasing at a slower rate than the United States
- ? Currently unable to assess rate of change in foreign capability vs. the United States

F. FUNDING

Table 10-7. Funding by Subarea
($ in Millions)

Subarea	FY92	FY93	FY94
Design Synthesis and Analysis	40	38	46
Production and Process Definition	10	14	20
Information Flow and Integration	15	26	18
TOTAL	65	78	84

Table 10-8. Funding by Program Element
($ in Millions)

PE No.	Title	FY92	FY93	FY94
0601101E	Defense Research Sciences	6.0	15.0	0.0
0601102A	Defense Research Sciences	9.0	8.0	8.0
0601102F	Defense Research Sciences	12.6	13.8	13.0
0601153N	Defense Research Sciences	1.3	1.3	1.3
0602201F	Aerospace Flight Dynamics	3.3	3.3	3.3
0602204F	Aerospace Avionics	0.5	0.8	0.7
0602205F	Personnel, Training, and Simulation	0.6	0.2	0.3
0602234N	Systems Support Technology	7.7	9.4	8.4
0602301E	Strategic Technology	15.0	15.0	20.0
0602602F	Conventional Munitions	2.0	3.0	3.0
0602702E	Tactical Technology	0.0	2.0	22.8
0602702F	Command, Control, and Communications	0.0	0.3	0.3
0602705A	Electronics and Electronic Devices	3.3	6.2	3.0
0602783A	Computer and Software Technology	3.2	0.0	0.0
	TOTAL	64.5	78.3	84.1

11. HUMAN-SYSTEM INTERFACES

A. DESCRIPTION OF TECHNOLOGY AREA

1. Scope

Human-system interfaces (HSI) are the key to operational effectiveness of most weapon systems. Indeed, it can be stated that there truly are no unmanned military systems. The scope of HSI is well beyond the traditional notions of workplace layout and "knobs and dials." The emphasis is on *systems* and the optimization of mission performance where the human is a critical element. A system broadly includes the weapon, operators, combat environment, and support structure. Recruitment, selection, assignment, training, protection, and safety of the human must also be considered. HSI requires a multidisciplinary approach, involving the fields of human factors, psychology, physiology, operations research, electronics computer sciences, and systems engineering. Science and technology investment within this framework can leverage high payoff in greatly improved system effectiveness in the future.

2. Human-System Interfaces Technology Subareas

a. Crew Stations and Operator Equipment

Relevant technologies are displays and controls; voice interaction; audio systems; head and helmet-mounted technologies; advanced concepts such as virtual reality and bio-adaptive interfaces; personal protective, life support, and safety equipment, which must be integrated cost effectively into crew stations such as cockpits, C^3I consoles, tank and ship operator stations, etc.

b. Information Management

This subarea encompasses information and decision aiding, automation support technologies. intelligent computer-based advisors and associates, human computer interaction, visualization and multimedia technology, distributed decision-making aids, computer-supported collaborative work, and other team technologies.

c. Design and Life Cycle Supportability

Included in this subarea are data bases of human sensory, cognitive, and control capabilities and limitations; data bases on the performance effects of operational stressors; metrics of complex behavior associated with mental workload, situation awareness, and decision-making; computational models, simulation, and field test evaluation techniques; CAD/CAE for enhanced human-system interface design; human performance visualization and simulation tools; and maintainability and logistics support analysis systems.

d. Manpower and Training

This subarea encompasses analysis of critical combat skills and development of personnel selection and classification tests; physiological standards; manpower decision support systems; classroom and embedded training technology; computer-based training and intelligent tutoring technology; individual, team, and unit training effectiveness metrics; distributed, interactive training simulation technology; and technologies for enhancing leadership, cohesion, motivation, and commitment.

3. Assessment

a. Crew Stations and Operator Equipment

The strategic goal is to improve the communications bandwidth between operators and systems by orders of magnitude. Current displays, both visual and auditory, severely constrain this bandwidth, resulting in a significant choke point. For example, the displays in a current cockpit are like viewing the world through a "bunch of soda straws;" the operator does all the integration and transformation in his brain. New large flat panel, helmet-mounted, and 3-D auditory display technology will dramatically open this channel and better match the sensory characteristics of the operator. This will lead to improved situational awareness needed for all weapon systems and support platforms. Future systems will have virtual reality capability and will adapt to the performance and physiological state of the human. Protective, life support, and safety equipment is needed for hostile environments; future systems must afford high levels of protection to minimize casualties. However, such protection must not interfere with the human's critical cognitive tasks.

b. Information Management

The information technology explosion offers tremendous opportunities for vastly improved systems. This same technology, however, produces an increasingly difficult challenge to the designer of the human operator–information system interface. This subarea centers on the human interface with automation, data bases, and computer-based systems. All future system operators will work in an information-rich environment; even the soldier will have his pocket computer, wirelessly networked with his or her team. Decision aids offer significant promise to improve decision quality, reduce workload, and, hence, crew size requirements. However, what and how to automate are critical, unanswered questions. Operators must understand and have confidence in future intelligent associates, or they won t use them and may be more prone to make errors. The future human-computer interface will be task oriented, allowing humans to work directly on their tasks, not with the host software. Properly human engineered visualization, multimedia, and hypermedia technology will enhance comprehension of large data bases. Adaptive, intent-based systems will have embedded models of operator behavior and goals. Finally, computer-supported collaborative work aids will greatly enhance team productivity, decision-making, and creativity.

c. Design and Life Cycle Supportability

This subarea will develop the tools of the trade and provide the infrastructure for system design. The HSI engineering design discipline requires considerable program emphasis in order to advance the state-of-the-art to the level of other engineering domains. At the foundation is the development of measures of complex human behavior and reliability, relating these measures to weapon system effectiveness, generation of the extensive empirical data bases, and finally development of computational models. Models of the human information processing system must be expressed in terms that are compatible with the systems being designed.

Historically, the human interface was considered late in the design of a system, often as an add-on. The operator was a slack variable, providing the needed flexibility in system operations. Today's highly integrated weapons require concurrent engineering of all subsystems including the human operator, maintainer, their interfaces, and logistics support. Accurate data and models of human perception, situation awareness, decision-making, and workload are needed to make this happen. In addition to controlled laboratory experiments, considerable data-gathering in part-task, part-mission, full-mission, field test, and military stress environments will be necessary.

Finally, in order for the information to be used by the design community it must be made available through the CAD/CAE workstation environment. We are rapidly approaching the era when all design sources and tools must be available on the designers CAD/CAE station—or it will not be used. Visualization, multimedia, and hypermedia techniques will greatly enhance the interpretation and understanding of the human-system interface design data. These new tools for design support will, for the first time, give engineers, designers, maintainers, users, and managers early insight into human interface considerations such as maintainability, crew performance and workload, crew station design, safety considerations, operator and maintainer skill requirements, training, etc. These design support tools can also be transferred to industry, where they will result in better products for DoD and a stronger and more competitive national industrial base.

d. Manpower and Training

Acquiring a trained warfighter is expensive—up to $7 million for a fully trained fighter pilot. In the wake of budget and manpower constraints, and the need for speed, agility, and rapid response, fewer crew members will have to operate at the pinnacle of their performance potential.

Specialized selection of people who can excel at critical skills needed for combat jobs can minimize the number of trainees who wash out later during instruction. Highly predictive physiological and psychological measures can also select personnel with the potential for completing a full career, realizing even more savings. The ability to keenly sense the environment and manually control weapons is important, but information processing and decision making skills, flexibility, stress tolerance, and ability to lead and perform in uncertain environments have become even more critical. Specific tests of these cognitive skills must be developed as well as the decision support systems to accurately place individuals in training programs. Once there, innovative cognitive training approaches, new leader technologies, and computer-based training will allow more people to achieve peak levels of performance.

Highly realistic, full-mission training simulations are also very expensive. Human-in-the-loop simulations don't have to reflect the real world, but they need to provide the information necessary for effective training. Fidelity criteria based on this human-centered approach can save dollars. Other tools, using AI and other advanced computer technology, will improve our ability to model entire manpower systems, thereby enhancing the precision of forecasts and policy implications. Leadership, motivation, and cohesion technologies will help build and sustain strongly led and well integrated small teams, combined arms, and joint Service units. Virtual reality technology offers the promise of reconfigurable, compact simulation systems at reduced cost.

B. TECHNOLOGY AREA GOALS

Quantification of payoff in the HSI area in many cases is difficult. A majority of the goals reflect the development of entirely new capabilities, lacking evolutionary trend data. Indeed, the development of better metrics for complex individual and collective human performance is one of the high priority research efforts, including the relationship with combat mission effectiveness. However, targets of opportunity abound in this key technology. To cite one example, over 60 percent of the $50 million of operations and support costs of a typical Air Force squadron is directly related to manpower and training. The new capabilities will improve the warfighter's sensing, information processing, stress tolerance, decision making flexibility, and control abilities to significantly enhance combat performance. Well led, cohesive, and committed units will be better prepared to meet the uncertainties in the future battlefield.

Table 11-1. Human-System Interfaces Technology Goals

Subarea	By 1995	By 2000	By 2005
Crew Stations and Operator Equipment	• Initial situation awareness displays. • Cost-saving standard designs. • Effective night vision.	• Integrated systems for high user operability. • Lightweight, comfortable helmet systems. • Improved multistressor protection. • Accurate spherical situation awareness.	• User adaptive controls/displays. • High information/control bandwidths. • High agility systems.
Information Management	• Operability by broader range of users. Improved data base comprehension. • Enhanced user acceptance. • Human error reductions.	• Routine tasks fully automated. • 20% workload improvements. • Timely, accurate tactical decisions. • Individual awareness amplification.	• Cut crews by one-half. • 50% workload improvements. • Force multiplication with virtual associates. • Team awareness amplification.
Design and Life Cycle Supportability	• First-generation crew station design support system. • Accurate design audit trail. • Widely accessible electronic data bases. • First systems engineering process.	• Design costs/time cut by one-half. • Empirically based design tradeoffs. Full user involvement in design. • Networked simulations used for design quantification.	• Concurrent, networked design environment. • Rapid, precision CAD evaluations.
Manpower and Training	• Order-of-magnitude cost reduction with part-task simulations. • 25% reduction in job-placement mismatch. • Streamlined job structures. • Improved leader development.	• Triple exchange ratios with multi-ship training. • Technical training to top 25% level. • 50% reduction in placement errors. • Validated training programs for all critical job tasks.	• Train to level of 10th wartime mission. • Cost savings through built-in training. • Near optimal tactical and strategic decision making.

C. RELATIONSHIP OF TECHNOLOGY GOALS TO THRUSTS

Table 11-2. Relationship of Human-System Interface Goals to Thrusts

Thrust \ Subarea	Crew Stations and Operator Equipment	Information Management	Design and Life Cycle Supportability	Manpower and Training
1. Global Surveillance and Communications	• User-friendly C^3I stations. • 3-D situation awareness for commanders.	• Surveillance management decision aids. • Transparent distributed data bases.	• Control station design tools.	• Battle management training systems.
2. Precision Strike	• Fully interactive mission-adaptive displays.	• Sensor data fusion. • Planning aids. • Target recognition aiding.	• Cockpit and C^3I station design technology.	• Attack skills training simulators.
3. Air Superiority and Defense	• All aspect pilot situation awareness. • Integrated helmet display/audio/life support.	• Routine tasks automated. • Pilot workload reductions to 50%.	• Cockpit and C^3I station design techology.	• Tailored part-task simulations. • Selection methods. • Situational awareness training.
4. Sea Control and Undersea Superiority	• Fully integrated crew stations.	• Distributed decision making aids. • Intelligent adaptive interfaces.	• Ship crew station design tools	• Decision making training under stress. • Team training technology.
5. Advanced Land Combat	• Low profile standard crew station. • Lightweight helmet system.	• One-half reduction in crews. • Lowered workload. • Combat vehicle intelligent associates.	• Land vehicle crew station design tools.	• Built-in training. • Integrated team/leader/unit training.
6. Synthetic Environments	• Total virtual reality systems. • Large format displays/graphics. • Improved graphical/user interfaces.	• Multimedia visualization. • High-fidelity graphics symbologies.	• Quantitative human performance measures. • Real-time automated measurement. • Computational behavior models.	• Identification of warfighting skills. • Cognitive skills training. • Distributed, interactive simulation networks for combat training.
7. Technology for Affordability	• Equipment designed around user capabilities and constraints.	• Design data fusion. • Designer-centered automation. • Inferential data base systems.	• Design data visualization. • Biofidelic human representations. • Multi-disciplinary computer-supported collaborative design. • Model-based analysis.	• Near zero placement errors. • Simulation fidelity based on specific training requirement. • System designs based on manpower and training capabilities.

D. SUBAREA ROADMAPS TO REACH TECHNOLOGY GOALS

Table II-3. Roadmap of Technology Objectives for Crew Stations and Operator Equipment

Technology Set	By 1995	By 2000	By 2005
Displays/Controls	• Intuitive multifunction capability. • Symbology standards. • Situation awareness display concepts. • Panoramic display demo.	• Real-time tactical maps. • Panoramic panel display. • High-speed display graphics.	• Fully interactive displays. • 3-D presentations. • Synthetic vision displays.
Voice Interaction/Audio	• 3-D audio flight demo. • Wireless intercom.	• Lightweight active noise reduction. • Modular digital audio.	• Totally interactive voice/audio systems.
Head Mounted Systems	• Lightweight night vision sensor image system. • High luminence miniature CRTs and flat panel displays. • Improved image intensifiers/optics.	• Full color helmet displays. • Lightweight miniaturized optics.	• Binocular helmet displays. • Visual/audio virtual reality helmet. • Night vision compatible helmet displays.
Advanced Concepts/ Integration	• GPS integration. • Prototype tactile devices. • Vehicle/crew station systems engineering capability.	• Fully integrated crew stations. • Standard crew station designs. • Helmet display/protection integration. • Physiologically-based monitoring and performance system.	• Bio-adaptive crew station. • Neurophysiological control. • Multimodal virtual reality system.
Protection/Life Support/ Safety Equipment	• Integrated anti-G protection. • Laser eye protection. • Fit/comfort criteria. • Directed energy CM design.	• Full G-protection/life support ensemble. • Hypersonic (3-5 Mach) escape criteria. • Smart personnel protection assembly. • 12-G protection. • Pharmaco-kinetic models of toxicity. • Improved diving decompression models.	• Manportable power. • Custom individual systems. • Integrated micro-environmental control. • Reactive underwater breathing gear.

Table 11-4. Roadmap of Technology Objectives for Information Management

Technology Set	By 1995	By 2000	By 2005
Decision Aiding	• Automated mission planning. • AI vehicle management algorithms. • Automated message I/O.	• Tactical combat aids. • Sensor fusion algorithms. • Computer-aided navigation. • Aided target recognition. • Integrated information portrayal.	• Intelligent associates. • Situation awareness advisors. • Auto target recognition. • Battle management automation.
Human Computer Interaction	• Direct manipulation interfaces. • Hypermedia data base interaction. • Eye/head coupled input.	• Natural language dialogue. • Transparent distributed data bases. • Intelligent architecture prototype. • Integrated task environment.	• Intelligent adaptive interfaces. • Biocybernetic interface.
Visualization	• Multimedia interfaces. • 3-D audio integration.	• 3-D animation. • Dynamic simulation.	• Virtual reality data base access. • Synthetic/real environment fusion.
Team Technology	• Electronic meetings. • Computer-supported collaborative work prototypes.	• Shared knowledge data bases. • Distributed decision making.	• Multidisciplinary collaboration. • Ultra wide band collaboration.

Table 11-5. Roadmap of Technology Objectives for Design and Life Cycle Supportability

Technology Set	By 1995	By 2000	By 2005
Human Performance Capabilities and Models	• Cognitive workload metrics. • Stress effects data bases. • Task performance models.	• Computational models of cognition. • Situational awareness and decision making metrics. • Manned threat models. • Vigilance monitors.	• Unobtrusive real-time measures. • Cognitive performance criteria.
Simulation, Test, Evaluation	• Criteria for part-task, part-mission, full-mission simulation. • Field test performance evaluation.	• Rapid interface prototyping. • Team performance metrics.	• Virtual prototyping. • Automated measurement. • Performance graphic workstation.
Interface CAD/CAE Tools	• First generation crew-centered design capability. • 3-D body surface imaging. • Multimedia human performance data base.	• Electronic prototyping of interfaces. • Human performance test benches. • 3-D CAD of interfaces.	• Virtual internetted design. • Intelligent design aids. • Computer-supported collaborative design systems. • Human animation. • Bio-fidelic electronic human.
Maintenance/Logistics	• Logistics management system. • Maintainability CAD program.	• Logistics/support distributed data base. • Dynamic maintenance simulations.	• Integrated life cycle decision support system.

Table 11-6. Roadmap of Technology Objectives for Manpower and Training

Technology Set	By 1995	By 2000	By 2005
Personnel Selection and Force Management	• Decision support system. • Identification of critical cognitive and non-cognitive skills. • Personnel assignment optimization technology.	• Cognitive and non-cognitive performance selection tests. • Physiological standards. • Personnel strength forecasting system.	• Comprehensive selection instruments. • Job-specific assignment tests. • Flexible career assignment system.
Computer-Based Training	• Cognitive job skills tutor. • Information management skills training. • Intelligent tutor design system.	• Training for tactical decision making under stress. • Automated instructional design system. • Integrated tutors/dynamic simulations.	• Built-in automated training. • Adaptive intelligent training devices. • Virtual reality/natural language capable intelligent tutors.
Training Simulation Technology	• Fidelity criteria. • Individual performance measures. • Part-task techniques.	• Minimum cost design criteria. • Multimedia simulation technology. • Multiship training.	• Real-time performance visualization. • Training strategies for simulator networks. • High-fidelity cognitive immersion simulators. • Low-cost reconfigurable simulators.
Leader Development	• Leader assessment technology	• Leader in unit performance metrics.	• Integrated unit and leader development technology.

E. R&D IN OTHER ORGANIZATIONS (GOVERNMENT, INDUSTRY, FOREIGN)

1. Government and Industry

Because of the complexity of the warfighter's task and system interface, the Services pioneered the HSI field and continue to lead in critical areas of enabling technology. Most of the other government agency work is being accomplished by the FAA, NASA, and the NRC. The FAA has a significant planned effort titled the National Aviation Human Factor Plan. The military was invited to help plan this program, and it is expected that the FAA will use Service laboratory expertise in the execution of the program. Its principal aims are to minimize pilot error and improve airspace management systems. NASA has programs in space life support, habitability, and crew station design for Space Station Freedom. In addition, NASA Ames Research Center has excellent capabilities in flight deck design. Major fixed and motion-based simulators are used to study pilot performance, flight control, and crew station layout issues. The NRC has emphasized control room design, automation issues, and displays (much of it motivated by nuclear power plant safety needs).

DoD Industry IR&D programs tend to emphasize weapon system procurement programs, concentrating on the crew stations, operator equipment, and interface software. State-of-the-art human computer interaction research is being done at Xerox-Parc, Bellcore, Apple, and IBM. A long-standing organization, the DoD Human Factors Technical Group, has accomplished coordination and information exchange among the Services and Industry. Semi-annual meetings are widely attended by the principal technologists and managers. Also the DoD-sponsored Crew Systems Ergonomics Information Analysis Center is actively involved as a gateway for HSI information for DoD, other agencies, and industry. It provides surveys, assessments, consulting, and a regularly published newsletter, in addition to other services. The private commercial sector lags the military in this key technology area. Recently, however, there has been a significant realization that HSI will be of major importance to future intelligent manufacturing and networked agile enterprise systems. Transfer of DoD technology can have big payoffs toward the competitive advantage of our future design and manufacturing infrastructure.

2. Foreign

The British are judged to have excellent programs in human factors design. British Aerospace Company is conducting research in such areas as the modeling of visual target acquisition, color science for displays, eye movement for control (tracking and switching), cognition and workload, and human-computer interaction. Firms in the U.K. are engaged in the development of an advanced HUD system with a large field-of-view using a so-called "head motion box." They are active in the design of HMD devices. The British have undertaken research on improving the communications link between the pilot and the environment. A flight deck simulator using large format electronic displays has been developed. British firms have built flight deck displays for a variety of Western transport aircraft that make use of advanced CRT, LED, and LCD devices.

The French have been engaged in a number of R&D programs since the mid-1980s aimed at the design of superior aircraft cockpits based on combining the latest in human factors research with the optimum use of modern electronic displays and controls. Aerospatiale has served as the coordinator for several of these programs: EPOPEE III was a major research effort from 1984 to 1990 to investigate pilot ergonomics; the program resulted in a new cockpit layout and short motion controls. FANSTIC was an eight-nation European effort that made use of sophisticated French simulators and a growing data base to develop new cockpit/flight deck controls and displays. PREFACE is an effort by Aerospatiale and other French companies to advance cockpit design. Other French firms are also doing advanced cockpit design work with a goal being to aid the pilot when disoriented. The French are designing the first tank outside of the CIS to use a three-man (vice four-man) crew.

In addition to work on the Tornado and the European Fighter Aircraft, Messerschmitt-Boelkow-Blohm of Germany has been engaged in developing new technology involving human factors and artificial intelligence with modern guidance and control concepts, and other advanced avionics and sensors. Germany is assessed to be a leader in designing weapons to fit operator performance.

Historically, coordination and information exchange between U.S. military labs and the Europeans has occurred through NATO Research Study Groups and the AGARD. Recent panels have addressed highly relevant topics such as modeling, situational awareness, and simulations. The TTCP also has an active Subgroup on Human Resources and Performance with groups focusing on aviation, C3, and training.

In support of the FS-X, a number of Japanese companies have been engaged in work on ergonomic cockpit design, artificial intelligence studies, large HUDs, and multi-function CRT displays. With the backing of their capable electronics industry, the Japanese should have minimal difficulty in executing competitive cockpit designs. Their work on artificial intelligence and other supporting technologies places them in a good position to produce effective human-system interfaces for most military systems.

Since the 1980s, Soviet aviation authorities have endeavored to overcome the human factors limitations of flight and deficiencies in the design of their aircraft cockpits. They established large well equipped laboratories and test facilities, and substantial progress has been noted in CIS cockpit design, flight simulation, and air traffic controller performance. In more recent times human factors concerns have expanded to embrace ground and naval systems as well. The CIS' extensive man-in-space research is thought to have resulted in a large data base on this topic. CIS scientists have given great consideration to psychological monitoring.

Since the late 1970s, the Israelis have assembled an effective group of companies to develop modern cockpit controls. They have constructed comprehensive facilities for test and simulation. Human factors projects involving ergometrics, workload analysis, display design, and cockpit illumination have been conducted. Their work on the Lavi combat aircraft has been the centerpiece of much of their development effort. Israeli companies have been leaders in the development of advanced helmet-mounted sights and heads-up displays. The Israeli Defense Forces possess a superior capability to match personnel with military occupational specialties. They have developed effective methods for monitoring the morale of their combat soldiers. The Israelis have paid considerable attention to the cooling of individual crewmen in combat vehicles as a means of reducing stress.

Table 11-7. Summary and Comparison — Human-System Interfaces

Subarea	NATO Allies	Japan	CIS	Others
1. Crew Stations and Operator Equipment	□□□□ O	□□□ O	□□	□□□ O Israel
2. Information Management	□□□ +	□□□ O	□□	□□ O Israel
3. Design and Life Cycle Supportability	□□□ O	□□	□□	□ Israel
4. Manpower and Training	□□□ O	□□	□□□ ?	□□□ O Israel
Overall[a]	□□□ O	□□	□□□ ?	□□

[a] The overall evaluation is a subjective assessment of the average standing of the technology in the nation (or nations) considered.

LEGEND:

Position of other countries relative to the United States:

- □□□□ Broad technical achievement; capable of major contributions
- □□□ Moderate technical capability; possible leadership in some technical niches; capable of important contributions
- □□ Generally lagging; may be capable of contributing in selected areas
- □ Lagging in all important aspects; unlikely to contribute prior to 2002

Trend indicators—where significant or important capabilities exist (i.e., 3 or 4 blocks):

- \+ Foreign capability increasing at a faster rate than the United States
- O Foreign capability increasing at a similar rate to the United States
- – Foreign capability increasing at a slower rate than the United States
- ? Currently unable to assess rate of change in foreign capability vs. the United States

F. FUNDING

Table 11-8. Funding by Subarea
($ in Millions)

Subarea	FY92	FY93	FY94
Crew Stations and Operator Equipment	97	37	36
Information Management	21	25	25
Design and Life Cycle Supportability	56	74	64
Manpower and Training	57	65	69
TOTAL	231	201	194

Table 11-9. Funding by Program Element
($ in Millions)

PE No.	Title	FY92	FY93	FY94
0601102A	Defense Research Sciences	7.0	7.5	8.0
0601102F	Defense Research Sciences	9.7	10.4	9.8
0601153N	Defense Research Sciences	10.0	11.0	12.0
0602122N	Aircraft Technology	1.3	1.9	2.1
0602201F	Aerospace Flight Dynamics	2.1	2.3	2.2
0602202F	Human Systems Technology	45.4	51.4	49.9
0602204F	Aerospace Avionics	1.1	1.2	1.2
0602205F	Personnel, Training, and Simulation	30.0	32.0	35.0
0602211A	Aviation Technology	2.2	2.2	1.9
0602233N	Mission Support Technology	14.7	19.5	23.8
0602234N*	Systems Support Technology	5.5	5.8	0.0
0602601A	Combat Vehicle and Automotive Technology	5.0	19.0	5.0
0602716A	Human Factors Engineering Technology	5.9	10.6	18.0
0602785A	Manpower/Personnel/Training Technology	15.9	16.0	15.3
060XXX3E	Flat Panel Display Technology	75.0	10.0	10.0
	TOTAL	230.8	200.8	194.2

*FY94 funding transferred to PE No. 602233N.

APPENDIX

APPENDIX

The Key Technologies were selected because of their importance to achieving the goals of the S&T Strategy thrusts. The 21 Defense Critical Technologies identified in the May 1991 Defense Critical Technologies Plan were selected through a much less focused process. However, there is considerable similarity between these two lists. Table A-1 presents the relationship of the two taxonomies. Some notes on the table:

- The table shows the extent to which the Critical Technologies map into the Key Technologies, not the other way around.
- The numerals reflect the extent to which a particular Critical Technology is covered by that Key Technology. The highest number (10) means that there is an almost perfect one-to-one mapping. The total column reflects how well that Critical Technology is covered by all of the Key Technology Areas.
- The total column shows that most of the Critical Technologies are addressed in one or more Key Technology Areas.
- Because the Key Technology Areas support the S&T Thrusts, they will generally contain topics not included in the Critical Technologies Plan.

Table A-1

CRITICAL TECHNOLOGIES	KEY TECHNOLOGIES: 1 Computers	2 Software	3 Sensors	4 Communications Networking	5 Electronic Devices	6 Environmental Effects	7 Materials and Processes	8 Energy Storage	9 Propulsion and Energy Conversion	10 Design Automation	11 Human System Interfaces	TOTAL FOR EACH CRITICAL TECHNOLOGY
1. Semiconductor Materials and Microelectronic Circuits					10							10
2. Software Engineering		10										10
3. High Performance Computing	10											10
4. Machine Intelligence and Robotics		2	2	2						2	2	10
5. Simulation and Modeling										5	5	10
6. Photonics			2		3							5
7. Sensitive Radar			10									10
8. Passive Sensors			10									10
9. Signal and Imaging Processing			10									10
10. Signature Control			1			1	4			4		10
11. Weapon System Environment						10						10
12. Data Fusion											10	10
13. Computational Fusion Dynamics										10		10
14. Air-Breathing Propulsion									10			10
15. Pulsed Power								10				10
16. Hypervelocity Projectiles and Propulsion								3	3			6
17. High Energy Density Materials								10				10
18. Composite Materials							10					10
19. Superconductivity	1		2		4		1	1	1			10
20. Biotechnology			2				2					4
21. Flexible Manufacturing										10		10

GLOSSARY

GLOSSARY

ADC	Analog-to-Digital Converter
AI	Artificial Intelligence
AMLCD	Active-Matrix Liquid Crystal Display
AMPP	Advanced Materials and Processing Program
ANN	Artificial Neural Networks
ARM	Anti-Radiation Missile
ASCM	Advanced Spaceborne Computer Module
ASUW	Airborne Anti-Surface Warfare
ASW	Anti-Submarine Warfare
ATD	Advanced Technology Demonstration
ATR	Automatic Target Recognition
BDA	Battle Damage Assessment
BICES	Battlefield Information Collection and Exploitation System
BTI	Balanced Technology Initiative
C-C	Carbon-Carbon
C3I	Command, Control, Communications, and Intelligence
CAD	Computer-Aided Design
CAE	Computer-Assisted Engineering
CAM	Computer-Aided Manufacturing
CASE	Computer-Aided System Engineering
CIS	Commonwealth of Independent States
CMOS	Complementary Metal Oxide Semiconductor
CONUS	Continental United States
CW	Continuous Wave

DAC	Digital-to-Analog Converter
DARPA	Defense Advanced Research Projects Agency
DB	Data Base
DBMS	Data Base Management System
DCE	Distributed Computing Environment
DDR&E	Director, Defense Research and Engineering
DDS	Direct Digital Synthesizer
DNA	Defense Nuclear Agency
DoC	Department of Commerce
DoD	Department of Defense
DoE	Department of Energy
DRAM	Dynamic Random-Access Memory
DRG	Defence Research Group (NATO)
EAST	EUREKA Advanced Software Technology
ECCM	Electronic Counter-Countermeasure
ECU	European Currency Unit
EHF	Extra-High Frequency
EL	Electroluminescent
EM	Electromagnetic
EO	Electro-Optics, Electro-Optical
EPA	Environmental Protection Agency
ESF	European Software Factory
ESPRIT	European Strategic Program for Research in Information Technology
ESSI	European Software and System Initiative
ETC	Electro-Thermo Chemical
EUREKA	European Research Coordination Agency
EW	Electronic Warfare
FAA	Federal Aviation Administration
FCCSET	Federal Coordinating Council on Sciences, Engineering, and Technology
FDS	Fixed Distribution System
FLIR	Forward-Looking Infrared
FPA	Focal Plane Array(s)
FSU	Former Soviet Union

FT	Fault-Tolerant
FY	Fiscal Year
GaAs	Gallium Arsenide
Giga-	Billion
GPS	Global Positioning System
HCI	Human-Computer Interaction
HDTV	High Definition Television
HEDM	High Energy Density Materials
HF	High Frequency
HFET	Heterostructure Field Effect Transistor
HHS	Health and Human Services (Department of)
HPC	High Performance Computing
HPCC	High Performance Computing and Communications
HPM	High Power Microwave
HSI	Human-System Interfaces
HTS	High Temperature Superconductor
IC	Integrated Circuit
IFF	Identification Friend or Foe
IHPTET	Integrated High Performance Turbine Engine Technology
IR	Infrared
IRFPA	Infrared Focal Plane Arrays
IRST	Infrared Search and Track
ISAR	Inverse Synthetic Aperture Radar
KB	Knowledge-Based
LADAR	Laser Radar
LAN	Local Area Network
LCD	Liquid Crystal Display
LNA	Low Noise Amplifier
LO	Low Observable
LPI	Low Probability of Intercept

MCC	Microelectronics and Computer Technology Corporation
MCM	Multichip Module
Mega-	Million
MHDL	Microwave Hardware Descriptive Language
MIMD	Multiple Instruction Multiple Data (Computer)
MIMIC	Millimeter Wave Monolithic Integrated Circuit
MLS	Multilevel Security
MMACE	Microwave and Millimeter Wave Advanced Computer Environment
MMIC	Microwave Monolithic Integrated Circuit
MMW	Millimeter Wave
MODIL	Manufacturing Operations Development Integration Lab
MPP	Massively Parallel Processor
MTI	Moving Target Indicator
MWIR	Microwave Infrared
NASA	National Aeronautics and Space Administration
NASP	National Aero-Space Plane
NATO	North Atlantic Treaty Organization
NCTR	Noncooperative Target Recognition
NIPT	New Information Processing Technologies
NIST	National Institute of Standards and Technology
NRL	Naval Research Laboratory
NSF	National Science Foundation
o/s	operating system
OEIC	Opto-Electronic Integrated Circuits
OLIVES	Optical Interconnections for VLSI and Electronic Systems
OS	Operating System
OSTP/COMAT	Office of Science and Technology Policy/Committee on Materials
OTH	Over-the-Horizon (Radar)
PDSS	Post-Deployment Software Support
Peta-	Quadrillion (10^{15})
PFN	Pulse Forming Network

PPM	Pulse Power Module
PRC	People's Republic of China
R&D	Research and Development
RAM	Random Access Memory
RCS	Radar Cross Section
RCVR	Receiver
RLC	Resistance Inductance Capacitance
RPV	Remotely Piloted Vehicle
RSG	Research Study Group (NATO)
RT	Real-Time
S&T	Science and Technology
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SBR	Space-Based Radar
SCEPS	Stored Chemical Energy Propulsion System
SDI	Strategic Defense Initiative
SEE	Systems Engineering Environments
SEI	Software Engineering Institute
SFC	Specific Fuel Consumption
SHF	Super-High Frequency
SIMD	Single Instruction Multiple Data (Computer)
SOS	Silicon on Sapphire
SPC	Software Productivity Consortium
SRAM	Static Random-Access Memory
SSGM	Strategic Scene Generation Model
SW	Smart Weapon
T/R	Transmit/Receive
Tera-	Trillion
TTCP	The Technical Cooperation Program
TTP	Theoretical Peak Performance
TWT	Traveling Wave Tube

UAV	Unmanned Air Vehicle
UGV	Unmanned Ground Vehicle
UHF	Ultra-High Frequency
UUV	Unmanned Underwater Vehicle
UWB	Ultra-Wideband
VHF	Very High Frequency
VME	Vacuum Microelectronics
XMTR	Transmitter